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SUB-TRENTON FORMATIONS IN OHIO

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ABSTRACT

A test hole with total depth 4,746 feet located near the axis of the Cincinnati arch in Ohio has revealed several new formations which are either Middle or Lower Cambrian or pre-Cambrian in age. Below the Lower Magnesian dolomite and Upper Cambrian sandstones are 100 feet of red sands and shales tentatively correlated with the "Red Clastic series" of Minnesota. Then follow 400 feet of arkose and dolomite, never previously found in this region, which are possibly Keweenawan. Below this the test penetrated over 800 feet of black, carbonaceous limestone which is considered to be pre-Cambrian. Tests drilled farther north on the axis reached granitic gneiss at 2,800 feet with both these latter formations omitted. This black limestone is unknown anywhere else in the Great Lakes region.

FRIEND WELL

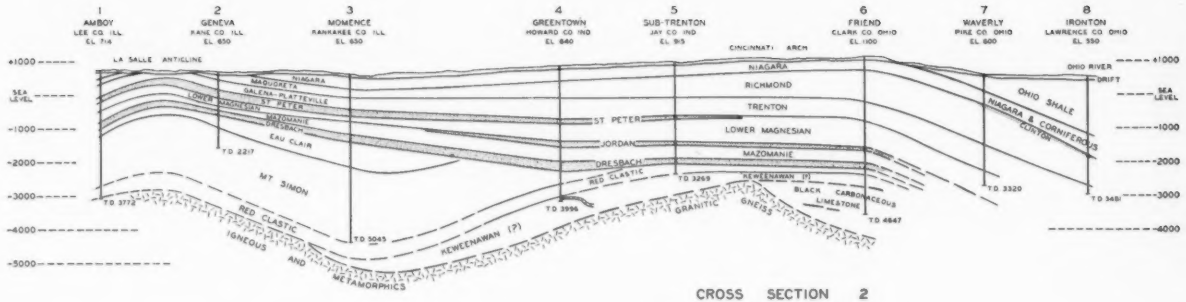
Sedimentary formations older than any previously known in Ohio have been discovered. During 1925 and 1926 T. D. Friend of Columbus drilled a test hole[1] located 11 miles southeast of Springfield, Ohio, near the axis of the Cincinnati arch, which penetrated to a depth of 4,647 feet (Sec. 1, No. 6). As the writer is the only geologist who followed the progress of the drilling continuously by a study of the samples and by talking with Friend, it seems desirable that the findings of this most interesting well, with an attempt at interpretation, should be made available for future reference. A set of samples is on file in the Geological Department of the Pure Oil Company, Chicago, Illinois.

The Friend well penetrates 2,792 feet of sedimentary rock below

[1] T. D. Friend, No. 1 Mattinson, 1¼ miles from South Charleston, 11 miles SE. of Springfield, Clark County, Ohio, completed 1927.

CROSS SECTION 1

NORTHERN ILLINOIS TO SOUTHERN OHIO



CROSS SECTION 2

CENTRAL INDIANA TO NORTHERN OHIO

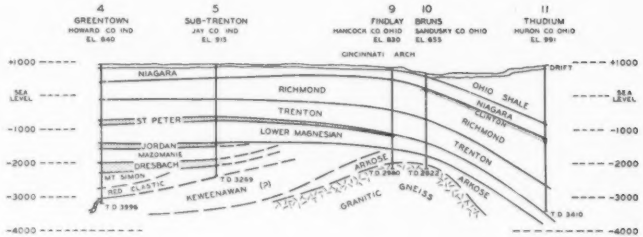


FIG. 1

the base of the Trenton–Black River Series. The first 800 feet, 1,855–2,655, are the Lower Magnesian dolomite of Chazy and Beekmantown age; a uniform, finely crystalline white dolomite. The next 764 feet, 2,655–3,419, are Upper Cambrian, consisting mostly of sandstone. The next 420 feet, 3,419–3,840, are either Cambrian or Upper Keweenawan gray dolomite, with some sandstone and arkose. The last formation is 807 feet, 3,840–4,647, of black carbonaceous limestone, probably pre-Cambrian. This formation has never previously been found in the pre-Cambrian sequence of the Mississippi Valley or the Lake Superior Region. The fact that it is a true limestone and not a dolomite is noteworthy and the fact that it is highly carbonaceous is important.

PREVIOUS KNOWLEDGE OF SUB-TRENTON FORMATIONS IN OHIO

Although many wells in Ohio have been drilled 50 feet or so below the Trenton, few have reached the deeper formations below it. A small, short-lived pool near Newark, Ohio, was developed in the top of the Lower Magnesian group, which occurs throughout Ohio immediately below the Trenton. The only other wells which add information on these older rocks are two at Findlay, Ohio[1] (Sec. 2, No. 9) which pass through about 400 feet of Lower Magnesian dolomite, below which is found 400 feet of arkosic sandstone and red shale. This is probably the "Red Clastic series" to be discussed later. Below the arkose the wells penetrate red granitic gneiss at about 2,800 feet. Since the Findlay wells are located on the axis of the Cincinnati arch and are about 85 miles north of the Friend well, the writer assumed when the Friend test was started that it would encounter a similar section.

EFFORTS AT CORRELATION TO THE SOUTH, EAST, AND NORTH

The correlation and identity of the formations below the Trenton became a problem on which the writer has worked at intervals for several years. During 1927 the Ohio Oil Company drilled a well on the Bruns farm,[2] Sandusky County, Ohio (Sec. 2, No. 10), 40 miles

[1] D. D. Condit, "Deep Wells at Findlay, Ohio," *Amer. Jour. Sci.*, 4th ser., Vol. XXXVI (1913), pp. 123–30.

[2] Ohio Oil Company, No. 1 Bruns, Sec. 9, T. 5 N., R. 13 E., Sandusky County, Ohio, completed 1927.

northeast of Findlay, which reached granitic gneiss at 2,672 feet, 725 feet below the base of the Trenton. The writer examined a set of samples taken every 5 feet from this well. The results are strikingly similar to those which Condit found in the wells at Findlay, mentioned above.

Correlation to the south with the Tennessee-Kentucky section is very difficult. The Cambro-Ordovician section there consists largely of the Knox dolomite. This dolomite, which is 3,000–4,000 feet thick, extends from the Upper Ordovician to the Middle Cambrian,[1] and hence is the equivalent of all the formations from the base of the Trenton to the bottom of the Cambrian in the Friend well. Being a lithologic unit with few fossils, it is not subdivided by most geologists.

Correlation to the east is difficult as the Trenton is one of the formations deeply buried in the Appalachian geosyncline, and where its equivalent is exposed it is far removed from Ohio.

Correlation northward in Michigan is hardly more fruitful. The formations descend from the Cincinnati arch into the Michigan basin. Where they emerge on the north and east rim, the formations below the Trenton have mostly disappeared. In the old Ontario oil field, north of Lake Erie, deep wells have shown that below the Trenton is an arkose ranging from 5 to 100 feet in thickness, below which pre-Cambrian gneiss is reached at a depth of about 3,700 feet.[2] The Lower Ordovician and Cambrian are, therefore, both missing. Across the St. Clair River in Michigan a well drilled in 1929 near Detroit reached the base of the Trenton at 4,600 feet and passed through 75 feet of gray sandstone called St. Peter, 20 feet of red shale, and 95 feet of red sand.[3] This basal red shale and sand suggests the Red Clastic series of Minnesota, first identified by C. R. Stauffer as at least in part Middle Cambrian.[4] The thick section of Lower

[1] Arthur Keith, "Roan Mountain Folio," *U.S. Geol. Surv. No. 151* (1907), p. 7.

[2] C. W. Knight, "Record of Wells Drilled for Oil and Gas in Ontario." *Ont. Bur. Mines, Twenty-Fourth Ann. Rept.*, Vol. XXIV, Part II (1915), and R. B. Harkness, "Natural Gas in 1929," *Ont. Dept. Mines, Twenty-Ninth Ann. Rept.*, Vol. XXXIX, Part V (1930), pp. 31, 35, 36.

[3] St. Clair Oil and Gas Co., Grange Hurst No. 1, Sec. 26, T. 5 N., R. 16 E., St. Clair County, Mich., completed 1929.

[4] C. R. Stauffer, "Age of the Red Clastic Series of Minnesota," *Geol. Soc. Amer. Bull.*, Vol. XXXVIII (1927), pp. 469–78.

Ordovician and Upper Cambrian is missing in eastern Michigan as in Ontario.

Another interesting deep test in Michigan, which may contribute information on the sub-Trenton formations, is a well now drilling in Ottawa County east of Muskegon.[1] This well reached below the base of the Trenton at 5,485 feet, a gray sand called St. Peter extending to 5,867 feet. Below this 400-foot sand body is sandy dolomite with oölitic chert. Correlation with the Lower Magnesian group is uncertain. Samples from this well and their determination are held confidential by the Michigan Geological Survey.

TEST HOLES TO THE WEST USED FOR CORRELATION

Correlation to the west brings more satisfactory results. In Indiana several deep wells have been drilled, the deepest of which is at Greentown, Howard County (secs. 1 and 2, No. 4). W. N. Logan, state geologist of Indiana, examined a set of samples taken at 5-foot intervals from this well and published a paper with his condensed log.[2] The sub-Trenton well, Jay County, Indiana (secs. 1 and 2, No. 5), is a second well which encountered the deeper formations.[3] As it is almost on the Indiana-Ohio state line, it gives the transition to the section farther west. However, Logan's classification of the formations, which followed E. O. Ulrich's work in Wisconsin,[4] did not fit the findings from the Friend well, and it was not until the writer got in touch with F. T. Thwaites, of the University of Wisconsin, that a satisfactory classification could be made. Mr. Thwaites has examined thousands of cuttings from wells in northern Illinois and Wisconsin and has studied the surface exposures of the formations below the Trenton in Wisconsin. Two of his publica-

[1] Michigan Petroleum Co., Charles E. Noe No. 1, Sec. 6, T. 9 N., R. 13 W., Ottawa County, Mich., completed 1930.

[2] W. N. Logan, "The Sub-Trenton Formations of Indiana," *Ind. Acad. Sci. Proc.*, Vol. XXXIV (1925), pp. 75–79.

[3] W. N. Logan, "The Geology of Deep Wells of Indiana," *Ind. Dept. Conservation, Div. Geol., Pub. 55* (1926), pp. 7–18, 256, 282.

[4] E. O. Ulrich, "Notes on New Names in Table of Formations and on Physical Evidence of Breaks between Paleozoic Systems in Wisconsin," *Wis. Acad. Sci. Proc.*, Vol. XXI (1924), pp. 71–107.

tions were especially helpful in this study,[1] and he was kind enough to examine the samples from the Friend well and to suggest correlation with the Illinois-Wisconsin section. Based on his classification, the Greentown and sub-Trenton well-sections of Indiana were reclassified and correlation with the Friend well thus made.

To tie to the Wisconsin-Illinois section, a test recently drilled near Momence, Illinois[2] (Sec. 1, No. 3), is included. Samples from this well which was completed in February, 1931, were examined by L. E. Workman, of the Illinois Geological Survey. The remarkable thing about this test is the 2,885 feet of Eau Claire and Mt. Simon sandstones. At its greatest depth, 5,045 feet, it was still in Mt. Simon. The report that the test reached granite has not been checked by Workman's findings. Another interesting well (Sec. 1, No. 1), called the Amboy well,[3] is included in the cross section. It is one of the two wells in Illinois which has reached granite. The Amboy well is located just west of the axis of the LaSalle anticline. Samples were not examined by Workman until 1930, when it was discovered that the well had penetrated the complete Cambrian section and entered the pre-Cambrian granite at a depth of 3,760 feet. This test had 1,750 feet of Eau Claire and Mt. Simon sandstone and 400 feet of Red Clastics over the granitic gneiss. The Geneva City well (Sec. 1, No. 4)[4] is included to show the transition between the Amboy and Momence wells.

SECTION FROM THE FRIEND WELL

CAMBRO-ORDOVICIAN SECTION

In the Friend well the first formation below the Trenton–Black River is the Lower Magnesian group, or Prairie du Chien formation of Lower Ordovician age. This formation probably includes the Chazy

[1] F. T. Thwaites, "The Paleozoic Rocks Found in Deep Wells in Wisconsin and Northern Illinois," *Jour. Geol.*, Vol. XXXI (1923); "Stratigraphy and Geologic Structure of Northern Illinois," *Ill. Geol. Surv. Rept. of Investigations, No. 13* (1927).

[2] Hughes Oil Co., No. 1 Parish, Sec. 24, T. 31 N., R. 13 E., Kankakee County, Illinois, completed 1931.

[3] Amboy Oil and Gas Co., No. 1 McElroy, Sec. 30, T. 20 N., R. 10 E. Lee County, Illinois, completed 1923.

[4] W. L. Thorne and Co., and J. P. Miller Artesian Well Co., No. 2, Geneva City, T. 39 N., R. 8 E., Kane County, Illinois, completed 1928.

and Beekmantown of the east. It is the oldest sedimentary formation previously encountered in Ohio with the exception of the arkose in the Findlay wells. It consists of a series of sandy dolomites, both the sand and dolomite being beautifully crystallized. The whole formation is remarkably white, free from impurities, and even in texture. It thickens rapidly eastward, averaging 300 feet in northern Illinois, 600 feet in Indiana, and 800 feet in the Friend well. The upper part of the formation may correlate with the St. Peter sandstone farther west or may be a sandy phase of the Lower Magnesian. The sand contains many large, rounded, etched grains typical of the St. Peter. The cuttings are easily mistaken for pure quartz and are so logged in most wells in Ohio. The "Blue Lick" is the typical water of the St. Peter farther west, but as water similar to this is found at other horizons in the dolomitic section, it is not a safe criterion for the St. Peter. The writer has concluded that it is very doubtful whether the St. Peter sandstone exists in Ohio. The Lower Magnesian group has been subdivided in northern Illinois into the Oneota dolomite, "New Richmond" sandstone, and Shakopee dolomite in ascending order. In Ohio and Indiana the formation is so homogeneous that it is impracticable to attempt subdivision.

The formation below the white crystalline dolomite consists of 455 feet of gray dolomites, subordinate amounts of sand and interbedded gray shale. This marks the top of the Upper Cambrian. It is easily separated from the white dolomite above by its gray-green color. In the upper 115 feet is a gray dolomite containing as high as 69 per cent white sand. This formation may correlate with the Madison or Jordan sandstone, or possibly the Trempealeau formation of northern Illinois and Wisconsin. It can be identified in the sub-Trenton and Greentown wells. In the lower 180 feet a conspicuous amount of glauconite, some pyrite, and biotite are found. This mineralized portion probably correlates with the Mazomanie of the Wisconsin section in which glauconite is abundant, making the formation a valuable marker in the geological column. This glauconitic bed can be definitely traced across Illinois and Indiana and is quite uniform in thickness, about 180 feet.

Below this is the Dresbach sandstone. It is the first true sandstone below the Trenton, all the other so-called "sands" being mostly

dolomites with some quartz. The Dresbach is correlated with certainty as it is a coarse white crystalline sand relatively free from cementing minerals and carrying water. In the Friend well it is 210 feet thick. Its average thickness in Indiana and Illinois is 150 feet. In the Chicago area it yields excellent water.

RED CLASTIC SERIES

Below the Dresbach is a series of fine red sands and shales about 100 feet in thickness which may be the Red Clastic series. In Wisconsin and northern Illinois between the Dresbach and Red Clastic series are the Eau Claire and Mt. Simon formations. The Eau Claire contains red, green, and gray shales, and dolomitic sandstones. The Mt. Simon is largely a red and gray sandstone. The sandstone below the Dresbach in the Friend well differs from these in being arkosic and non-dolomitic. However, since red shales and sands are common in the Eau Claire of the Milwaukee region, its correlation with the Red Clastic series of Minnesota must not be considered final. From 3,366 to 3,370 is a sticky hematite clay. At the base of this series are 9 feet of coarse granite sand with much pink feldspar. In the Findlay well Condit[1] describes the 410-foot sand above the granite as arkosic in upper portion, with garnet, orthoclase, microcline, and plagioclase plentiful. At the base he reports a red, green, and gray clay. A red shale similar to that mentioned in the Friend well occurs near the base of the sub-Trenton well at 3,100 feet. In the Greentown well the last 490 feet may also belong to this red sand and shale series. Dr. Logan classifies the last 100 feet as Algonkian, noting that a 20-foot diabase dike was intersected. In the Amboy well, Lee County, Illinois, the last 400 feet before going into granite are red sands, thin red shales, and arkosic sands. The Red Clastic series, which reaches 2,000 feet in thickness in Minnesota, is also found in Wisconsin and Michigan. It is differentiated from the overlying Upper Cambrian sands by the presence of non-dolomitic, red shales, and more or less arkosic material.

The Red Clastic series has been considered by some to be of Keweenawan age, probably because the beds are similar to the red sandstone and arkose interbedded with lava flows in the Lake Supe-

[1] *Op. cit.*

rior region.[1] Previously, Winchell considered them Upper Cambrian in age and used the term "Potsdam" for the whole series.[2] Since the series is a land deposit and non-fossiliferous, it is difficult to determine the age. Lane thinks that the Keweenawan is not necessarily pre-Cambrian in age, but that it may continue upward without break into the Cambrian.[3] Stauffer's recent discovery of Middle Cambrian fossils in the Red Clastic series gives new light on its age. In a well near Waconia, Minnesota, he discovered and identified minute fossils which proved to be some of the same species described by Walcott from the Middle Cambrian of Montana.[4] If the correlation of the Red Clastics in the above wells is correct, it would prove the existence of Middle Cambrian strata in Illinois, Indiana, and Ohio, where only Upper Cambrian was previously recognized.

GENERAL CORRELATION

In examining cross section No. 1, it should be noted that in going west from the Friend well a rapidly thickening section of Cambrian sands appears between the Dresbach and the Red Clastic series; in the Greentown well there are 415 feet, in the Momence well, 2,885 feet, and in the Amboy well, 1,740 feet. These formations including the Eau Claire and Mt. Simon consist of gray, yellow, and pink sandstone. Their type locality is near Eau Claire, Wisconsin, where the Mt. Simon forms an escarpment which is capped by Eau Claire shaly sandstone. According to Thwaites, the Mt. Simon must be the basal member of the Cambrian over a wide area of drift-covered country in central Wisconsin.[5]

To summarize: the Cambrian system in Illinois, Indiana, and Ohio is made up almost entirely of sandstone with thin shale breaks. The upper formations, consisting of the Jordan, Trempea-

[1] C. E. Hall, O. E. Meinzer, and M. L. Fuller, "Geology and Underground Waters of Southern Minnesota," *U. S. Geol. Surv., Water Supply Paper 256* (1911), pp. 48, 366.

[2] N. H. Winchell, "Natural Gas in Minnesota," *Minn. Geol. Surv. Bull. 5* (1889), p. 25, also *Geol. of Minn.*, Vol. IV (1899), pp. 567–71.

[3] A. C. Lane, "Keweenawan Series of Michigan," *Mich. Geol. Surv. Publication 6*, Vol. II, p. 940.

[4] C. R. Stauffer, "Age of Red Clastic Series of Minnesota," *Geol. Soc. Amer. Bull.*, Vol. XXXVIII, pp. 474–75.

[5] F. T. Thwaites, "The Paleozoic Rocks Found in Deep Wells in Wisconsin and Northern Illinois," *Jour. Geol.*, Vol. XXXI (1923), pp. 551–53.

leau, Mazomanie, and Dresbach, are quite uniform in thickness across the area, making a total of 300–400 feet. The Jordan is a white sandy dolomite occurring just below the Lower Magnesian. The Trempealeau and Mazomanie are identified by the glauconite and red, green, and gray calcareous shales. The Dresbach consists of a medium white sandstone. Below these formations in Illinois and Indiana are about 1,500 feet of sandstone called Eau Claire and Mt. Simon. These formations are medium- to fine-grained sandstones with some thin shale layers. They thin rapidly from the Indiana-Ohio state boundary line eastward until they have disappeared in the Friend, Burns, and Findlay wells in central Ohio. The formations above are all Upper Cambrian. The red sandstone, which may correlate with the Red Clastic series, ranges from 100 to 400 feet in thickness, and extends from Illinois to Ohio. It may be Middle or Lower Cambrian, possibly in part Keweenawan.

PRE-CAMBRIAN FORMATIONS

The formations below the Cambrian in the Friend well consist of 1,228 feet of sedimentary rock. The correlation of this section can only be suggested in the broadest terms. First, is 145 feet, 3,472–3,617, of hard, dark gray or black dolomite. After treatment with hydrochloric acid, considerable gray feldspar, sand, and magnetite remain. From 3,617 to 3,840 is a gray arkose with thin shale layers. This formation may be Upper Keweenawan.

Below these is the most interesting formation in the entire section—a black carbonaceous limestone which was penetrated 800 feet, from 3,840 to the total depth, 4,647. This formation is unusual, because it is limestone and because it contains much free carbon. Limestones are rare in the pre-Cambrian. Professor R. J. Colony, of Columbia University, made a microscopic examination of twelve samples from this formation. The drill chips were made into pats with Portland cement, and after proper curing and hardening, thin sections were cut, thus giving actual thin sections of the fragments. Summarizing his report,[1] he found from 4,072–4,085 a black, more or less shaly, carbonaceous limestone, somewhat fractured and healed with clear calcite. From 4,365 to 4,382 is an arkosic bed,

[1] R. J. Colony, "Memorandum on Drill Chips," made privately for the author, July, 1931.

composed entirely of fragments of much altered igneous rock, most of them intensely sericitized, some of them carbonated. Many of the fragments are pieces of quartz porphyry containing characteristic corroded quartz phenocrysts. From 4,400 to the total depth, 4,647, is again the black carbonaceous limestone which has been fractured and healed with clean calcite. Fine pyrite is distributed in the black carbonaceous matter, which itself is disseminated through the limestone. There are also numerous round, black, phosphatic nodules, filled with fine pyrite.

Since the nature of the abundant black carbonaceous matter had been in doubt and since the dolomitic content of the limestone was also questioned, Mr. Colony gave especial attention to these two questions. He says, "the black limestones, heated in closed tubes, give off fumes and an organic, or 'burned' odor, not, however, like bitumen. It is a pyroligneous odor." He concludes by saying, "I am certain that the black color . . . . is due in large part to carbonaceous matter, and in part to 'organic' matter . . . . and in part to the round and oval, black phosphatic nodules." As regards dolomite he says:

> I have determined the magnesia content in some of the samples and in no case is it high enough to warrant calling these samples dolomites. The magnesia content ranged from 0.24% to 1.79%. Due to the fact that some of the magnesia with some of the lime was precipitated as phosphate in the phosphatic nodules, the results on magnesia are low. However, this would not increase the magnesia content more than twice. Though the magnesia content were three or four times as much as the determinations show, it is not sufficient to make dolomite out of these rocks.

This series of pre-Cambrian limestones was most unexpected considering the igneous rock found in other wells immediately below the Cambrian sediments. The igneous rock in the Findlay wells is described by Condit as granite,[1] probably gneissoid. Biotite and green hornblende are the principal accessory minerals with a considerable amount of titanite and apatite and a lesser amount of garnet. The Bruns well entered similar igneous rock at 2,672 feet. A piece of rock from the Bruns well is now in the Ohio State Museum, Sample No. 16450, dimensions $1\frac{1}{2}$ inches $\times \frac{3}{4}$ inch $\times \frac{1}{4}$ inch.

[1] *Op. cit.*

FRIEND WELL

DETERMINATION FROM SAMPLES

Drift (118 feet)	0–118	
Niagara (245 feet)	118–363	
Richmond (882 feet)	363–1,245	
Trenton, and Black River 1,245–1,855 (610 feet)	1,245–1,410	limestone
	1,410–1,415	very fine texture, black shaly ls., white ls. streaks, fragments brachiopod shells
	1,423–1,428	finely crystalline, light gray ls., fossiliferous
	1,445–1,450	hard, white, fine-grained crystalline ls.
	1,465–1,470	light gray dense ls., irregularly crystalline
	1,475–1,480	dense, buff colored chalky ls.
	1,495–1,500	dense gray-brown ls. with bentonite fragments
	1,510–1,515	dense gray-blue ls.
	1,530–1,535	finely crystalline, hard light gray-brown ls.
	1,575–1,580	same as preceding sample
	1,625–1,630	dense gray-blue ls.
	1,645–1,650	finely crystalline, gray-brown ls.
	1,685–1,690	finely crystalline hard white ls.
	1,715–1,720	same as preceding sample
	1,725–1,730	dense gray ls., crystalline in places—smell of oil
	1,785–1,790	same as preceding
	1,835–1,840	dense, dark gray ls.
Lower Magnesian, 1,855–2,655 (800 feet)	1,855–1,860	hard, white, dense ls.
	1,880–1,883	white, finely crystalline ls.—show water
	1,885–1,890	tan, finely crystalline ls.
	1,895–1,900	dense gray-brown ls. with some green shale
Chazy and Beekmantown	1,925–1,928	"Green Pencil Cave" sh., light greenish-gray (not bentonite)
	1,945–1,950	dol., gray, very slight pink tinge, pyritic
	1,995–2,000	fine white crystalline dolomite, pyritic
	2,030–2,035	same as preceding—fragments of green shale cavings —(bentonite?)
	2,055–2,060	same as preceding—very fine quartz ss. "Blue Lick Water Sand"
	2,105–2,110	same
	2,125–2,130	same, with bentonite (Thwaites says may be white chert)
	2,145–2,150	same
	2,155–2,160	same, pyritic
	2,185–2,190	same, some white specks
	2,195–2,200	same
	2,205–2,210	coarser chips, still finely crystalline dol.
	2,260–2,265	dol., light gray
	2,280–2,285	very fine white dol., gray bentonite caving
	2,295–2,300	same

FRIEND WELL—*Continued*

Lower Magnesian—*Cont'd*	2,320–2,325	same
	2,380–2,385	same
	2,414–2,420	dol., white
	2,440–2,445	dol., light gray, some white
	2,455–2,460	coarsely crystalline dol.
	2,485–2,490	dol., same, bentonite chips, caving
	2,545–2,550	same, very hard
	2,570–2,575	same, hard with chunk light greenish-gray shale, either from bit or caving
	2,625–2,630	dol., light gray, very hard—5–7 hours
	2,650–2,655	same
Jordan and Trempealeau, 2,655–2,770 (115 feet)	2,680–2,685	60 per cent white sand, 40 per cent iron-stained dol.
	2,688–2,720	samples missing
	2,720–2,725	gray ls., dol., small amount sand
	2,745–2,750	gray limy dol., small amount fine sand, gray ls.
Mazomanie, 2,770–3,110 (340 feet)	2,770–2,775	shale, dark gray; some gray dol.; pyrite and sandy shale and gray ls.
	2,795–2,800	same
	2,825–2,830	gray dol.
	2,855–2,860	shale, light gray, dolomitic, greasy
	2,875–2,880	shale and dark gray dol.
	2,895–2,900	dol., dark gray to light gray with much shale like above
	2,932–2,938	dol., light pinkish gray, 80 per cent sand, glauconitic
	2,940–2,945	ss., glauconitic with pyrite, biotite, secondary quartz, some fragments very coarse
	2,990–2,995	ss., white to gray, grains subangular and irregular in size, pyrite, much dark shale, glauconite
	3,065–3,078	gray and white ss. and dol.
	3,079–3,087	same—glauconite
	3,087–3,094	sand, limy, iron staining
	3,100–3,105	dol.
Dresbach 3,110–3,320 (210 feet)	3,110	sand
	3,135–3,140	clear, sharp, crystalline sand with some dol.
	3,175–3,180	ss., fine gray dol., iron-stained
	3,190–3,195	same
	3,205–3,210	ss., limy, clear white crystalline quartz, very hard, gas
	3,210–3,216	same, iron-stained from tools, about 40 per cent red dolomite
	3,230–3,232	ss. and dolomite, iron-stained, some grains etched
	3,240–3,245	ss. fine to medium, white, some very light pink, some etched
	3,265–3,270	water sand, very fine, well sorted, pure ss.
	3,295–3,300	same, water ss.
	3,315–3,320	ss. very fine

FRIEND WELL—*Continued*

Red Clastics, 3,320–3,419 (99 feet)	3,330–3,335	ss. medium to fine, light gray, part cemented by a red non-dolomitic substance, probably shale
	3,335–3,340	ss., fine, light gray
	3,346–3,349	same
	3,349–3,353	ss., medium to fine, white
	3,355–3,360	same
	3,360–3,366	ss., medium to fine, light gray, and red shale
	3,366–3,370	sticky hematite clay—shale, dark red
	3,370–3,375	running sand, slightly calcareous, red, white, pink quartz
	3,410–3,419	granite sand—coarse ss., feldspar, pink, and light gray set $5\frac{3}{16}$
Upper Keweenawan (?), 3,419–3,840 (421 feet)	3,472–3,500	dol., black, very fine cuttings which on treatment with HCl leave considerable gray feldspar, ss., and black magnetite
	3,435–3,540	same
	3,572–3,577	dark gray dolomite
	3,577–3,818	no samples
	3,818–3,823	sand, very fine, gray, angular grains, probably an arkose or graywacke
	3,827–3,832	same
	3,835–3,840	dark gray dolomite
Pre-Cambrian black carbonaceous limestone, 3,840–4,647 (807 feet)	3,840–4,067	no samples
	4,067–4,072	a black, shaly, carbonaceous limestone, somewhat fractured and healed with clear calcite, fine pyrite disseminated through the carbonaceous matter
	4,080–4,085	same
	4,085–4,360	no samples
	4,360–4,365	fragmental rock composed of much altered fragments of igneous rocks such as quartz porphyry, heavily sericitized
	4,368–4,374	same
	4,374–4,378	same
	4,378–4,382	same
	4,395–4,400	black carbonaceous limestone with veins of clean calcite—much black carbonaceous matter in which fine pyrite is distributed—numerous round black phosphatic nodules filled with fine pyrite
	4,440–4,445	same, black phosphatic nodules more numerous
	4,458–4,463	same
	4,465–4,470	finely granular limestone, cleaner than those above
	4,470–4,474	very "dirty" finely crystalline limestone—splintery black carbonaceous grains, a few chert fragments, some of which carry fine pyrite, others little quartz grains and carbonate patches—many phosphatic nodules
	4,487–4,492	same
	4,521–4,526	same
	4,526–4,530	same—some of the black matter in the grains of limestone have the appearance and structural relations of introduced matter cutting across the grains of limestone as though filling weaknesses and fractures
	4,647½	T.D.

The rock is gneissoid granite, having a pink matrix of quartz and microcline with streaks of biotite mica and green hornblende. The drillings showed that the rock was not homogeneous. From 2,672 to 2,767 the rock was highly acidic, probably an aplite, with pure microcline, quartz, and streaks of biotite. From 2,767 to 2,787 the rock was a hornblendite with green hornblende and biotite. Quartz and plagioclase feldspars were present in subordinate amounts. From 2,787 to the total depth, 2,822, the rock was again a pink biotite granite. The Greentown well also encountered igneous rock. At 3,895 it passed out of the thick section of Cambrian sandstone into the Upper Keweenawan according to Logan. Fifty feet in this sandstone the well encountered 20 feet of diabase, probably a sheet or dike. Below this was 30 feet of sand to the total depth of 3,996 feet.[1] The Amboy well entered red granitic gneiss at 3,760, going in 12 feet. Thus the Cambrian of Illinois, Indiana, and western Ohio rests directly on a pre-Cambrian granitic gneiss.

The fact that the Friend well does not penetrate granite at the base of the Cambrian, but passes through more than a thousand feet of sedimentary or metamorphic rock, hitherto unknown, calls for some explanation. The shallow granite on the axis of the Cincinnati arch at Findlay and at the Bruns well suggests that a pre-Cambrian granite ridge follows the axis. This would separate the area east and west into two basins with different sedimentary histories. The fact that the Eau Claire and Mt. Simon are present on the west in thick sections and apparently absent on the east, and also the presence of a thick limestone below the Red Clastic series on the east, which is lacking on the west, strengthens this suggestion.

[1] *Op. cit.*, p. 256.

EVIDENCE INDICATING THE LIMITS OF TRIASSIC IN KANSAS, OKLAHOMA, AND TEXAS

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ABSTRACT

The paper discusses correlation of the highest red beds which have been called Permian in Kansas, Oklahoma, and Texas. Evidence is presented suggesting the Triassic age of these beds, and for them the new formation name "Custer"[1] is proposed. Previous literature has been briefly reviewed and annotated, showing the complexity of the problem and difficulty of correlations based upon individual beds. Regional correlations are made with the Black Hills, Wyoming, Colorado, west Texas, and New Mexico. These correlations would have been impossible were it not for samples obtained from deep borings. The petrography, petrology, and paleontology of beds known to be of Triassic age and of the Custer formation are reviewed.

INTRODUCTION

In the mid-Continent area of central Texas, Oklahoma, and Kansas, there is no pronounced stratigraphic break from the base of the Virgil series[2] of the Pennsylvanian up to the base of the Custer formation. Like the unconformity at the base of the Virgil, the unconformity at the base of the Custer increases as the distance from the Rocky Mountains decreases, except in Texas. The realization of these regional unconformities has been more and more forcibly impressed upon the writer as deep borings have been made. As a result of the westward march of the drilling of deep wells lithologic changes and fossil types began to appear, such as could not be found in the Permian and Pennsylvanian outcrops of Oklahoma and Kansas. For a time there was no adequate explanation for these conditions, and it was thought by many that strata occurred in this western area which did not crop out along the eastern strike of the Permian and Pennsylvanian beds. The interpretation of the age of these beds has varied greatly among sedimentary petrographers and micropaleontologists, and it may be said that it still does, which is no more than natural, as no two workers will interpret the evidence deduced from

[1] Name available according to records of the Committee on Geologic Names, U.S. Geological Survey.

[2] "A Proposed New Type Section of the Pennsylvanian System," by R. C. Moore, presented at G.S.A. meeting, Tulsa, Oklahoma, December, 1931.

a series of strata in exactly the same way. As a result of the questions and problems involved, it has been the writer's good fortune to make many extensive field trips extending over the past four years. As an inevitable outcome of this work, the problem of the Triassic has come up again and again, i.e., as to how much of the so-called Permian red beds is Triassic? If the Triassic is present in these red beds, where is its base? If not present, how far eastward does it occur beneath the Tertiary, Cretaceous, and Jurassic overlaps? In endeavoring to find some suitable answer to the above questions, studies were made in the field of the Spearfish, Minnekahta, and Opeche formations occurring in the Black Hills of South Dakota, the Lyons, Lykins, Forelle, and Satanka along the eastern front range of the Rocky Mountains in Colorado, the red beds of questionable age which are exposed as isolated inliers in the Panhandle of Oklahoma, the Dockum beds of the Panhandle of Texas, the Santa Rosa and Chinle beds of eastern New Mexico, and the Bissett formation of the Marathon region of west Texas. Studies were also made of the Moenkopie, Shinarump, and Chinle of western New Mexico and in the Grand Canyon region of northwestern Arizona and in southern Utah. With this field work as a background, the writer's chief purpose in the following pages is to review all facts that are available indicating the Triassic age of sediments here called Custer. A brief annotated revision of previous reports is included.

The Custer formation is the name herein proposed for those red beds which in Kansas occur between the Dog Creek shales and the Lower Cretaceous or Comanche group. It occupies the same interval in Oklahoma except where the Dog Creek shales are absent, in which case the Custer may rest upon various members of the Blaine or Flower-Pot shales. In Texas the Custer occupies the interval between the base of the Memphis sandstone and Santa Rosa conglomerate, or between the shales which overlie the Croton gypsum and the Camp Springs conglomerate or Comanchean at Double Mountain, Texas. In west Texas the Custer is equivalent to the interval between the Santa Rosa conglomerate and the Capitan limestone or top of the Carlsbad limestone. The name is from Custer County, Oklahoma, where almost the whole formation is well exposed.

HISTORY OF NOMENCLATURE

The Triassic of eastern New Mexico comprises the uppermost part of the red beds. The strata of varying thicknesses are composed of reddish-colored sandstones and conglomerates with variegated shales. Triassic vertebrate remains have been found by Stanton[1] near Folsom, and by Lee[2] at a point southeast of Tucumcari, and by the writer in Sec. 19, T. 31 N., R. 30 E., Union County, New Mexico. Probably the first authentic description of the Triassic in the southern great plains is that of Mt. Tucumcari ("Pyramid Mountain"), observed by Marcou[3] and described by Blake.[4] Marcou considered the base of Mt. Tucumcari to be formed of beds of the superior Trias. Cragin,[5] in 1891, considered the gypsiferous red beds of the Panhandle of Oklahoma as probably of Triassic age. Cragin,[6] in 1896, split the Cimarron group into two stages: an upper, or Kiger, and a lower, or Salt Fork. The Kiger stage which is of interest in this paper was divided into the following members which are as follows, starting at the base: Dog Creek shale, Red Bluff sandstone, Day Creek dolomite, Hackberry shale, and Big Basin sandstone. Cragin here assumed the Kiger to be of Permian age, which assumption is based upon the paleontologic evidence from the Clear Fork horizon of Texas and the middle Enid horizon in Oklahoma.

In 1897[7] Cragin placed the Dog Creek shale in the Salt Fork stage. Also the gypsum exposed west of Beaver City, Beaver County, Oklahoma, was named the "Beaver gypsum." Its stratigraphic position was determined as well up in the Kiger stage. The name "Taloga

[1] T. W. Stanton, "The Morrison Formation," *Jour. Geol.*, Vol. XIII (1905), p. 665.

[2] W. T. Lee, "Red Beds of the Rio Grande Region in Central New Mexico," *Jour. Geol.*, Vol. XV (1907), p. 55.

[3] W. F. Cummins, "Geology of Tucumcari, New Mexico," *Sci.*, Vol. XXI (1893), pp. 282–83.

[4] W. P. Blake, *Report on the Geology of the Route, Explorations, and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean*, War Dept. Route near the thirty-fifth parallel, Lieutenant A. W. Whipple, Vol. III (1856), pp. 25–26.

[5] F. W. Cragin, "A Leaf-Bearing Terrane in the Loup Fork," *Amer. Geologist*, Vol. VIII (1891), p. 29.

[6] F. W. Cragin, "The Permian System in Kansas," *Colo. College Studies*, Vol. VI (1896).

[7] F. W. Cragin, "Observations on the Cimarron Series," *Amer. Geologist*, Vol. XIX, No. 5 (1897), pp. 351–63.

formation" was proposed for those beds of the Kiger stage which are above the Day Creek dolomite. In speaking of Oklahoma Cragin stated that the dolomites capping the red bluffs at Watonga are the Day Creek.

Subsequent to the work by Cragin, in 1897, certain changes have been necessary in his nomenclature. It has been found that his Beaver gypsum,[1] Red Bluff sandstone,[2] and Hackberry shale[3] were preoccupied. The Big Basin sandstone in coming south into Oklahoma thickens up and includes several sandstones, and the Beaver gypsum can now be traced south into what Gould later called the Cloud chief.

Gould,[4] in 1902, changed a part of Cragin's classification and, in 1905,[5] explained these changes in considerable detail. The name "Woodward formation" was proposed for those beds which occur between the Blaine and the Greer. It was divided into three members —Dog Creek shale, Whitehorse sandstone, and Day Creek dolomite —which were all recognized and named by Cragin from localities in Kansas. For "Red Bluff" the name "Whitehorse" was substituted. The Whitehorse sandstone member is named from Whitehorse Springs found about 16 miles west of Alva, Oklahoma. Above the Woodward is the Greer formation and for the purpose of description it was grouped into two areas, an eastern and a western. These two areas were lithologically dissimilar. The members of the western Greer of the 1902 report were, starting at the base, Kiser gypsum, Chaney gypsum, Haystack gypsum, Cedartop gypsum, Collingsworth gypsum, and Delhi dolomite. In the report of 1905 the series is as follows: Chaney gypsum, Kiser gypsum, Haystack gypsum, Cedartop gypsum, Collingsworth gypsum, and Mangum dolomite. There are no explanations for these changes. The highest formation described by Gould is the Quartermaster.

[1] Comstock and Dumble, *Tex. Geol. Surv., 1st Ann. Rept.* (1890), pp. 259–306.

[2] E. W. Hilgard, *Report on the Geology and Agriculture of Mississippi* (Jackson, 1860).

[3] S. Calvin, *Ia. Geol. Surv.*, Vol. VII (1896), p. 163.

[4] C. N. Gould, "General Geology of Oklahoma," *Okla. Dept. Geol. and Natural Hist., Second Biennial Rep.* (1902), pp. 17–74.

[5] C. N. Gould, *Water Supply Paper, No. 148* (1905), pp. 52–77.

In western Texas, Cummins[1] distinguished the Dockum group; but the best description is by Drake,[2] who recognized three different stratigraphical units, but did not name them. The middle member, that is, the one of predominate conglomerate, correlates with Darton's Santa Rosa and, in turn, with the Shinarump; this member contains the dolomite conglomerates which have been referred to as clay balls by Lee. This dolomite conglomerate facies is especially well exposed in Union County, New Mexico, where it contains vertebrate remains so characteristic of the formation elsewhere. The strata are largely fresh-water deposits, and their age has been determined on vertebrate remains by Cope.[3]

Gould,[4] working on the Panhandle of Texas, describes the oldest Permian red beds exposed and correlates them with the Greer formation. Above the Greer formation Gould finds the Quartermaster formation containing in the lower part a gypsum lentil, which he named the Saddlehorse gypsum lentil. (The writer believes that the Saddlehorse gypsum lentil belongs with the underlying Blaine or Permian. The unconformity at the base of the Custer will explain its absence in many places.) From the upper part of the Quartermaster formation Gould describes the Alibates dolomite lentil. Above the Quartermaster were the Dockum beds. Vertebrate fossils from these beds are of Triassic types and are described by Simpson.[5]

In speaking of the unconformity which separates the Quartermaster from the Dockum, Gould states:

> There is a continuous unconformity at the top of the Quartermaster formation which everywhere separates it from the overlying Dockum beds. The upper limit of the Quartermaster, however, is in most places rather regular and there is but little evidence that any considerable erosion took place previous to the deposition of the Triassic sediments. The red shales which form the upper part of the Quartermaster formation above the Alibates dolomite lentil are relatively

[1] F. W. Cummins, *First Ann. Rept. Tex. Geol. Surv.* (1889), pp. 189–90.

[2] N. F. Drake, "Stratigraphy of the Triassic Formation of Northwest Texas," *Third Ann. Rept. Tex. Geol. Surv.* (1892), pp. 227–31.

[3] E. D. Cope, "Report on the Paleontology of the Vertebrata—Triassic or Dockum Beds," *Third Ann. Rept. Tex. Geol. Surv.* (1892), pp. 257–59.

[4] "The Geology and Water Resources of the Western Portion of the Panhandle of Texas," *Water-Supply and Irrigation Paper No. 191* (1907), pp. 14–29.

[5] C. T. Simpson, "Description of Four New Triassic Unios from the Staked Plains of Texas," *Proc. U.S. Nat. Mus.*, Vol. XVIII, No. 1072 (1896), pp. 381–85.

uniform in thickness throughout the region, and in only one locality, so far as observed, have they been entirely removed, so that the Triassic beds rest directly upon the dolomite.

This would indicate the absence of any pronounced uplift at this period. The Dockum beds are divided into two formations, the lower one being called the Tecovas formation. The upper is called the Trujillo formation and is largely a conglomerate. In this sandstone and conglomerate, vertebrate remains have been found which belong to a belodont probably *Phytosaurus superciliosus* Cope.

In 1920 Moore[1] in describing the geology of Kansas used the same nomenclature as was used by Gould, mentioning, however, the fact that Beede in recent studies had showed that a very important unconformity exists at the base of the Whitehorse sandstone and suggested that the Whitehorse should be separated from the Dog Creek shale and the latter placed with the underlying Cave Creek division of the Permian. The Greer formation includes all of the red beds above the Day Creek dolomite. (The Permian fossils of the Greer of Oklahoma led Beede to correlate the Whitehorse with the Permian.) The fact that the Hackberry shale is preoccupied by an Upper Devonian formation of Iowa is mentioned. It was called an unnamed shale member below the Big Basin sandstone.

Clapp,[2] working in Oklahoma, proposed the new name, "Cyril gypsum," correlating it with the Blaine formation. This placed the Whitehorse sandstone in the Enid or Permian, as the Cyril gypsum overlies it. Reeves[3] showed that the Cyril gypsum should belong in the eastern area of the Greer formation as it overlies the Day Creek dolomite.

Sawyer,[4] working in Oklahoma, found it necessary to introduce a new term, the "Marlow formation." It is overlain by the Whitehorse

[1] R. C. Moore, "Geology of Kansas," *Bull. 6, Geol. Surv. Kan.*, Part II (1920), pp. 71–73.

[2] F. G. Clapp, "Geology of Cement Oil Field," *Amer. Insi. Min. and Metallurgy, Eng. Bull. 158*, Sec. 27 (1920), pp. 3–4.

[3] F. Reeves, "Geology of the Cement Oil Field Caddo County, Oklahoma, *Bull. No. 726-B, U.S. Geol. Surv.* (1921), pp. 47–56.

[4] R. W. Sawyer, "Areal Geology of a Part of Southwestern Oklahoma," *Bull. Amer. Assoc. Petr. Geol.*, Vol. VIII, No. 3 (1924), pp. 313–19.

sandstone and underlain by the Duncan. Speaking of the Cyril gypsum, he says:[1]

> It appears, however, that these gypsums are neither the Blaine nor can they be connected with the gypsums along the bluffs of the north fork of the Red River where Gould found his section of the Greer [also Blaine]. They form a higher series as shown by the fact that the Duncan-Marlow contact, when traced north and west, passes above the Blaine and above the Greer (western area), but below the Cyril gypsum. The Blaine and the Greer (western area) seem to be the same formation but on opposite sides of a large syncline.

Sawyer's attention was called to this synclinal depression causing this new correlation by Greene[2] and by Beede. Mention is also made for the first time of channel sandstones which occur in the Marlow some 80 feet above its base. It would seem from field work that, in defining the Marlow, Sawyer wished to place those beds containing the channel sandstones in the Whitehorse; however, his definition of the formation includes them.

Ohern's[3] chief contribution consisted in placing the base of the Whitehorse at the top of the Duncan sandstone. This probably led Sawyer to divide the Whitehorse into two members: the one being the sandstone as described by Reeves, and the other, the lower, being the Marlow formation. Gould[4] immediately followed these authors with a new and simpler classification.

The salient points of Gould's classification were as follows:

> 1. Two new formations, the Duncan and the Chickasha, occupying the same stratigraphic position as the upper part of the Enid, have been added. 2. A peculiar sandstone in the Dog Creek shale (Marlow), which has the appearance of a stream channel, is recognized. 3. The name "Woodward" is abandoned. The consensus of opinion now is that the major subdivisions of the Permian should be based on unconformities at the base of the Quartermaster, Whitehorse, and Duncan (?), rather than on the presence of gypsums, as suggested in the old classification. One of the unconformities occurs in the middle of the Woodward formation, as that term was formerly used. 4. The name "Greer" is abandoned, it having been shown that the rocks formerly described as the western area of

[1] *Ibid.*, p. 317.

[2] F. C. Greene, *Oil and Gas Jour.*, May 7, 1920, p. 54.

[3] D. W. Ohern, *Bull. Amer. Assoc. Pet. Geol.*, Vol. III (1919).

[4] "A New Classification of the Permian Redbeds of Southwestern Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. VIII, No. 3 (1924), pp. 325–40.

the Greer are in fact the stratigraphic equivalent of the Blaine, Dog Creek, Whitehorse, and Cloud Chief. For the so-called eastern area of the Greer the term "Cloud Chief formation" is proposed.

This disposes of the "Cyril" gypsum. In this paper the Chickasha formation is described as lying above the sandstone series of the Duncan, which would place it in part of Sawyer's Marlow member, and the matter is further confused by his statement:[1] "This zone [speaking of the Blaine] represents the basal part of the Marlow formation, as the latter term has been known locally by Sawyer and other geologists." Again speaking of the Dog Creek shale,[2] it is described as occurring in the upper part of the Marlow formation as described by Sawyer. Speaking of the channel deposits,[3] "An unusual phase of the Dog Creek formation is a line of very peculiar fossiliferous, conglomeratic, sandstone exposures, which have the appearance of an old stream-channel occupying a more or less definite horizon in the upper part of the formation." This sandstone is usually spoken of locally as the "Channel sandstone," or the "Footprint sandstone." The name "Verden sandstone"[4] was later given to these channel deposits. Gould further corrects his previous statements[5] as follows: "The writer now believes that the dolomite which forms the summit of the red bluffs at Greenfield, Blaine County, is not Day Creek, as first indicated by Cragin, but is, in fact, a dolomitic member occurring in and not far above the base of the Whitehorse. The typical Day Creek occurs in the vicinity of Thomas, some 20 miles west of Greenfield."

The Double Mountain formation of Texas was first named by Cummins,[6] who, in working with the Permian formations in Texas, named three divisions, starting at the base, the Wichita, Clear Fork, and Double Mountain. The Double Mountain formation includes everything from the San Angelo to and including the Quartermaster.

[1] *Ibid.*, p. 335.

[2] *Ibid.*, p. 334.

[3] *Ibid.*, p. 335.

[4] R. D. Reed and N. Meland, "The Verden Sandstone of Oklahoma," *Jour. Geol.*, Vol. XXXII (1924), pp. 150–67.

[5] C. N. Gould, "A New Classification of the Permian Redbeds," *op. cit.*, p. 336.

[6] "Texas Permian," *Trans. Tex. Acad. Sci.*, Vol. II (1897), pp. 93–98. Also Ann. Repts. Geol. Surv. Tex., 1889–92.

The earliest and perhaps most complete treatise dealing only with the Whitehorse sandstone is by Clifton,[1] who strongly stressed the unconformity at its base. Clifton found that Gould's Quartermaster formation as described in the Panhandle of Texas is in reality the Whitehorse and contains at its base the fossil horizons occurring at Dozier in Collingsworth County, Texas, and is a part of the same system of stream channels which are found in several places in Oklahoma. Very complete lists of fossils were also given from seven different stream channel localities.

Following this paper is one by Stephenson[2] which deals with a phase of the Whitehorse, the Verden sandstone. The Verden is quite remarkable in its "shoe-string" nature which extends for a distance of over 70 miles, running in a southwesterly direction through the town of Verden, Oklahoma. Its occurrence is placed at about 35 feet below the base of the Whitehorse, which would be in the Marlow shale. Stephenson correlates the Marlow shale with the Dog Creek and Blaine gypsum. The Day Creek dolomite which was supposed to cap the hills at Greenfield is proved by field evidence to be some 250 feet below the true Day Creek, and the name Greenfield limestone is proposed for these beds. Where it occurs on the outcrop there are two members, and Stephenson[3] states that in his belief the Greenfield limestone is the stratigraphic equivalent of the Verden sandstone. The Greenfield limestone is preoccupied by a Silurian dolomite named by Grabau in 1898, which is found at Greenfield, in Allen County, Ohio. From the writer's observations the Greenfield limestone is a dolomite and lithologically strongly resembles the Day Creek dolomite; furthermore, it is not at the base, but up in the Custer, as the sandstones below the "Greenfield" dolomites are identical with those above.

After writing the paper mentioned, Stephenson heard a presentation of a paper by Clifton, and draws the following conclusions:[4]

[1] R. L. Clifton, *Areal Extent and Stratigraphy of the Whitehorse Sandstone*, unpublished thesis at the Univ. Okla., June, 1925.

[2] C. D. Stephenson, "Observations on the Verden Sandstone of Southwestern Oklahoma," *Amer. Assoc. Petr. Geol.*, Vol. IX, No. 3 (1925), pp. 626–31.

[3] *Ibid.*, p. 629.

[4] *Ibid.*, p. 631.

It appears from this paper and from a conversation with Beede that at the type locality at Whitehorse Springs, Gould includes a channel sandstone lying below a massive sandstone in the name "Whitehorse." Gould places the Verden sandstone in the Dog Creek formation. . . . . It does not seem advisable to the writer to include two formations so dissimilar as the Verden sandstone, a channel deposit, and the massive Whitehorse sandstone, a blanket deposit 250 feet thick, under the same formation name. These two formations are separated by about 35 feet of shale, containing locally some gypsum beds. . . . . If, however, because of priority the name "Whitehorse" for these formations has preference, it is here suggested that three divisions be made as follows: Upper Whitehorse, consisting of the massive, fine-grained, poorly cemented sandstone about 250 feet thick. . . . . The middle Whitehorse would include the red shale and gypsum directly under the massive sandstone and above what has been called "Verden" sandstone. . . . . The lower Whitehorse would include the channel sandstone or its stratigraphic equivalent, which locally has been called the "Verden" sandstone.

Hence Gould's Whitehorse proposed for Cragin's Red Bluff includes beds beside the Red Bluff.

In bringing the Triassic sediments into the general area from the west and southwest across New Mexico, perhaps the best reference is by Darton,[1] who carries over from the northwestern part of New Mexico the following nomenclature, starting at the base: Moenkopie, Shinarump conglomerate, and the Laroux formation. Later work by Gregory[2] has shown the desirability of changing the name "Laroux" to "Chinle." The Moenkopie was long thought to be Permian, but fossils found by Butler[3] in its extension into Utah and by Reeside in Arizona show it to be of Triassic age.

Carrying this tripartite nomenclature eastward, certain difficulties are encountered, and the equivalents stratigraphically are not absolutely proved. According to Darton the Shinarump conglomerate is probably represented in Huene's[4] Poleo sandstone from the

[1] N. H. Darton, "Geological Structure of Parts of New Mexico," *Bull. 726-E, U.S. Geol. Surv.* (1922).

[2] H. E. Gregory, "Geology of the Navajo Country," *U.S. Geol. Surv., Prof. Paper No. 93* (1917), pp. 42–48.

[3] W. B. Emery, "The Green River Desert Section, Utah," *Amer. Jour. Sci.*, 4th ser., Vol. XLVI (1918), p. 560.

[4] F. von Huene, "Kurze Mitteilung über Perm, Trias und Jura in New Mexico," *Neues Jahrb.*, Beilage Band XXXII (1911), pp. 730–39.

type at Poleo Mesa. Above the Poleo sandstone are shales which probably belong to the Chinle formation, and underlying the same sandstone are about 1,000 feet of red shales and sandstones which doubtless in part include Moenkopie. Coming farther east in New Mexico, that is, about Glorieta Mesa and the Hills of Pedernal, the strata overlying the Chupadera consists of 800 feet or more of red shales and sandstones representing the Dockum group, and near the bottom a resistant massive sandstone which is prominent along the Pecos River at Santa Rosa. This sandstone occurs about the same horizon as the Shinarump conglomerate and was called the Santa Rosa sandstone by Darton. Case has found Triassic bones in the overlying strata and in this sandstone, while Darton reports unios in the shales overlying the sandstone 1 mile north of Santa Rosa. In regard to the underlying shales, Darton states,[1] "It appears likely, however, that most of the shales overlying the Chupadera formation are of Triassic age." These shales attain a thickness of several hundred feet in Eddy and Chaves counties, New Mexico. The age of these beds has also been discussed by Beede[2] who shows that they are above the Guadalupe group of limestones and may be of Lower Triassic age.

Before considering the very interesting paper by Hoots,[3] a most striking similarity of deposition is to be noted in comparing the salt basin of southwest Texas with the deposits at Stassfurt, Germany; even the cycles of deposition are very well shown from a study of well samples in Andrews County, Texas, and Lea County, New Mexico. Continental deposits were swept over the areas forming the Lower Triassic series of early Mesozoic age both in Germany and west Texas. Eolian Custer lithology is to be noted locally in the lower part of the salt series in west Texas, starting at a rather marked point in the upper part of the dolomites, immediately underlying which Permian fossils are found. In the dolomites at Stassfurt, Germany, Permian fossils are also found just below the Bunter. In the paper by

[1] *Op. cit.*, p. 183.

[2] J. W. Beede, "The Correlation of the Guadalupian and the Kansas Sections," *Amer. Jour. Sci.*, 4th ser., Vol. XXX (1910), pp. 131–40.

[3] H. W. Hoots, "Geology of a Part of Western Texas and Southeastern New Mexico, with Special Reference to Salt and Potash," *Bull. 780-B, U.S. Geol. Surv.* (1926).

Hoots a peculiar composition of the sea which deposited the upper salts of west Texas is well shown; these salts are the only ones that contain potash in any commercial quantity. Samples of salt from the Wellington formation, Permian, in Kansas and Oklahoma, and the lower salts from the Panhandle of Texas, also Permian in age, were analyzed with nothing but traces of potash being present. Hoots believes that the salts of southwest Texas fall in the Double Mountain formation, though he did not say which part. In discussing the general stratigraphy of the area, Hoots concludes that the dolomite, etc., of the Rustler and probably the massive Castile gypsum grade laterally toward the east and southeast into the salt and anhydrite series. Discussing the characteristics of the Dockum beds, note is made to the effect that they are different lithologically from those described by Gould. The difference between the Dockum in this part of Texas and the Dockum in the Panhandle of Texas may be explained by lateral gradation. Both vertebrate and invertebrate remains of Triassic age have been found in this formation. Hoots[1] states: "It is not possible to separate the Permian red beds from the Triassic on the basis of a marked difference in color, a method found useful by Gould in the Panhandle."

Clifton,[2] in further work upon the Whitehorse sandstone, says that the Day Creek dolomite has not been found south of the Red River of Texas, but he has been able to trace the formation into the Alibates dolomite thus proving that the underlying Quartermaster is in reality the Whitehorse sandstone. The Whitehorse is correlated with the Lake Trammel sandstone in the vicinity of Sweetwater, Texas.

Beede[3] makes some very interesting correlations of the Whitehorse fauna with beds in the Trans-Pecos region. He says:[4]

> This correlation is that of the Whitehorse sandstone fauna with the Capitan or its equivalent west of Lakewood, New Mexico. This fauna occurs in the Whitehorse sandstone which is separated from the Blaine formation below by a rather thick shale known as the Dog Creek shale, and by what is probably a

[1] *Ibid.*, p. 92.

[2] "Stratigraphy of the Whitehorse Sandstone," *Oil and Gas Jour.*, June 3, 1926.

[3] J. W. Beede and D. D. Christner, "San Angelo Formation and the Geology of Foard County," *Univ. Tex. Bull. No. 2607* (1926).

[4] *Ibid.*, p. 14.

profound disconformity. This same fauna has been found in a formation near the top of the Capitan limestone in New Mexico. This would place it higher than the Marathon section, probably in the Gillian or Tessey.

Gould[1] again described the Cloud Chief with considerable detail. Concerning the age of the Cloud Chief he states:[2]

> The same red beds which occur in Beaver County containing the same gypsum ledges, may be traced practically uninterrupted into southeastern Texas County where along Palo Duro Creek a mile or two east of Range Post Office, there are exposures of red clays with interbedded gypsums more than 10 feet thick. It is the belief of the senior author that the red beds exposed along Beaver Creek near Redpoint and near Tepee Creek, as well as those along the Cimarron River northeast of Boise City, Cimarron County, are also of Permian age, and not of Triassic age.

The writer believes from field evidence that these gypsum beds overlie the Whitehorse zone and are equivalent to the overlying Day Creek zone in part. The writer's ideas along this matter are borne out by a personal communication from Clifton in which he states that the Day Creek dolomite in its most westward outcrop is found in T. 4 N., R. 25 E. C.M. Clifton also noted that the Day Creek dolomite grades laterally westward into gypsum, and this gypsiferous series occurs above the Whitehorse including the preoccupied Hackberry shale, the Big Basin sandstone, and perhaps others. With this in mind, and since the Day Creek dolomite is not a good bed on which to base a formation as Gould has done with the Cloud Chief, the writer believes that there is no way of retaining the Cloud Chief as a formational name; if used at all it should be as a zone.

Gould[3] here wishes to correlate the Cloud Chief with the preoccupied Hackberry shales of southwestern Kansas and the Quartermaster of Oklahoma with the Big Basin of Kansas. In 1927 Gould and Willis[4] correlated the Cloud Chief with the Castile, in part.

The questionable age of the Bissett, described by King,[5] led the

[1] C. N. Gould and J. T. Lonsdale, "Geology of Beaver County, Oklahoma," *Bull. No. 38, Okla. Geol. Surv.* (1926).

[2] *Ibid.*, p. 21.

[3] C. N. Gould and F. E. Lewis, "Permian of Western Oklahoma and the Panhandle of Texas," *Circular 13, Okla. Geol. Surv.* (1926).

[4] C. N. Gould and R. Willis, "Tentative Correlation of the Permian Formations of the Southern Great Plains," *Bull. Geol. Soc. Amer.*, Vol. XXXVIII (1927), pp. 431–42.

[5] P. B. King, "The Bissett Formation, A New Stratigraphic Unit in the Permian of West Texas," *Amer. Jour. Sci.*, Vol. XIV, No. 5 (1927), pp. 212–21.

writer to examine these beds which occur on the north side of the Glass Mountains of Texas. It was found to rest upon the Tessy, the Gilliam, and Vidrio, thus proving its marked unconformable relationship to the older rocks. From field evidence the writer believes these beds at the type locality of Bissett Mountain to be of Comanche age.

Darton[1] again sets forth the same points which were used in Bulletin 726-E:[2] "East of the Rio Grande the Chinle formation (Upper Triassic) is represented in the Dockum group, which occupies most of the eastern third of the State. Near or at its base is a conspicuous sandstone which I have named the Santa Rosa sandstone . . . . and may probably be an eastern extension of the Shinarump conglomerate." Farther on, Darton states that the upper part of the Chupadera formation includes red beds which contain Permian vertebrates in places, but the great majority of the overlying red beds is of Triassic age. Concerning the Moenkopie formation, Darton is not positive that it is absent east of the Rio Grande and states as follows:[3] "Although the red rocks of the Pecos Valley of southern New Mexico are probably of Permian age, it is possible that strata of lower Triassic age are also present." In discussing the Dockum group, mention is made of the sand near the base which is called the Santa Rosa sandstone; this is in turn underlain by red shales which overlie the Chupadera formation. Carrying the section southward from Santa Rosa, it is believed that these lower red shales thin out and the Santa Rosa sandstone constitutes the base of the group.

Evans[4] described briefly the surface geology about Weatherford, Oklahoma, and divides the Whitehorse sandstone into an upper and lower member. The writer was unable to find a definite line of contact between these two members of the Whitehorse, and field work shows that the lower part of the Whitehorse as described by Sawyer, that is, the Marlow member, really belongs with the underlying Dog Creek and Flower-Pot shales, as the contact between it and the Whitehorse may definitely be shown in a great number of places. As

[1] " 'Red Beds' and Associated Formations in New Mexico," *Bull. 794, U.S. Geol. Surv.* (1928).

[2] Ibid., p. 28.

[3] *Ibid.*, p. 29.

[4] N. Evans, "Stratigraphy of Weatherford Area, Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XII, No. 7 (July, 1928).

to just which of the dolomites at Weatherford is the Day Creek dolomite is extremely difficult to determine because of the rapid change in intervals and the occurrence of four different dolomites, any one or all of which may grade laterally into gypsum or anhydrite.

In discussing the highly complex literature of the Trans-Pecos region and southeastern New Mexico, correlations have been made in so many different directions that it is almost impossible to straighten out the difficulty.

In 1929, Keyte[1] made a statement which is quite valuable and bears out the paleontological evidence which the writer has been able to accumulate from field work. This evidence is the finding of *Schwagerina uddeni* and *S. fusilinoides?* 600 feet above the top of the Abo red beds in the Little Hatchet Mountains of New Mexico. The writer has been able to find this same zone in the Wolfcamp, in the Hueco, in the Sierra Diablo Mountains, and in the Chase formation from wells in western Oklahoma. *S. fusulinoides?* has been found in the Florence Flint of Kansas and Oklahoma on the outcrop. The equivalence of these beds is important because of some of the correlations which will be brought out in succeeding papers.

Crandall[2] gives a very good résumé of the stratigraphy, noting several things of importance. Mention is made of the finding of a conglomerate at the mouth of McKittrick Canyon, which apparently overlies the Delaware Mountain formation and underlies the Castile. This conglomerate occurs above the Frijole limestone and whether or not it marks an unconformity at the base of the Castile or the Capitan cannot definitely be determined. Darton[3] believes this conglomerate to be probably of late Tertiary age. (On the west face of the Guadalupe Mountains there is a little conglomerate at the base of the Capitan limestone.) This conglomerate[4] may be the same one to which Crandall refers in his statement that the gypsum series is everywhere separated from the Carlsbad limestone by a conglomerate or by a zone of re-worked red shale and gypsum. Crandall be-

[1] I. A. Keyte, "Correlation of Pennsylvanian-Permian of Glass Mountains and Delaware Mountains," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIII, No. 8 (August, 1929).

[2] K. H. Crandall, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIII, No. 8 (August, 1929).

[3] Personal communication.

[4] *Ibid.*, p. 940.

lieves that the Carlsbad limestone grades laterally into gypsum and red shale series which overlies the Queen sand. Further mention is made also of the Castile and Capitan series.[1] At the point of closest contact between the two formations each retains its own characteristics. The only calcareous part of the Castile series is at its base, where the gypsiferous limestones are distinctly granular and may be derived from the erosion of the topographically high Capitan as well as from inorganic precipitation. In fact, the juxtaposition of the Castile upon the Capitan is so close that one may throw a stone from one to the other. As a result, the Capitan limestone gives the aspect of an inlier. Crandall restates the equivalence of the Capitan and the Vidrio, Gilliam, Tessey formations, and mentions the similarity to the Schlern dolomites of Triassic age of southern Tyrol, Austria.

Lloyd and Thompson[2] made further additions to the already superabundant nomenclature. They group Whitehorse and Cloud Chief together as one formation and place its base at the base of the Childress dolomite. (This immediately leads to difficulties, as the sands above and below this bed look alike.) A new term is brought out which is the Memphis sandstone; it is reported to be something similar to the Verden sandstone and occurs 250 feet above the base of the Whitehorse sandstone as they place it. (The writer believes that the Memphis sandstone is a continuation of the Dozier Hills, which are channel deposits, and marks the base of the Custer.) Above the Memphis sandstone occurs the Sweetwater dolomite, another new term. It is very near the base of the Quartermaster and is only locally present. The Quartermaster formation is described as being well bedded and containing gypsiferous shales, with a possible unconformity at its base.

Blanchard's and Davis'[3] correlations of west Texas are as follows:[4] It is suggested that the Yeso and Bone Springs limestone are the

[1] *Ibid.*, p. 943.

[2] A. M. Lloyd and W. C. Thompson, "Correlation of Permian Outcrops on Eastern Side of the West Texas Basin," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIII, No. 8 (August, 1929).

[3] W. Grant Blanchard, Jr., and M. J. Davis, "Permian Stratigraphy and Structure of Parts of Southeastern New Mexico and Southwestern Texas," *Bull. Amer. Assoc. Geol.*, Vol. XIII, No. 8 (August, 1929).

[4] *Ibid.*, p. 970.

same and are equivalent to the Leonard, and that the Upper Yeso is equivalent to a part of the Delaware sandstone, with a possibility of the Bone Springs being equivalent to the Upper Abo. Also it is upon the presence of ammonites that a correlation is made between the Upper Delaware sandstone and the Word formation. (The writer's studies of the *Schwagerininae* and *Fusulininae* do not substantiate some of the above correlations. *Schwagerinas* are not found above the Wolf-camp of the Glass Mountains except as detrital in the basal conglomerates of the Leonard, called "Hess." This, of course, will place the San Andreas or Bone Springs below the Delaware sandstone or below the unconformity which is so well exposed over the top of the Bone Springs arch. The *Polydiexodinas* in the Delaware sandstone are not found in any part of the type Leonard.)

Later work upon the paleontology and lithology of the Word indicates the desirability of placing its base at the base of the sandy conglomeratic facies occurring below the Vidno. This roughly marks the base of *Polydiexodina* and *Waagenoceras*, and makes the Word equivalent to the Delaware sandstone.

(Due to the difficulty of traversing the terrane north of the Guadalupe Mountains, the tracing of the Chupadera into the Delaware sandstone is problematical. All paleontologists who have studied the fauna of the San Andreas will agree that it is older than the Delaware sandstone fauna. The lenticular nature of the Delaware and Capitan series northward is due partly to its overlapping nature and partly to removal by pre-Castile erosion. It may be demonstrated by deep borings that the Delaware and Capitan series becomes beveled off as one goes northeast of Roswell toward Clovis; anhydrites increase in thickness as the Delaware and Capitan decreases. The difficulty with placing the Queen sand on the unconformity between the Capitan limestone and the Castile gypsum is that there are several sands, all of which are called Queen, and they are hard to trace over the country. The Queen sand is overlain by the Seven Rivers gypsum, which some writers believe to be the lateral gradation of the Carlsbad. The writer's observations in Rocky Arroyo, Last Chance, and Sitting Bull Canyons show the equivalence of the Castile and Seven Rivers gypsum. Beede reports fossils in the Queen sand zone resembling the fauna of the Whitehorse sandstone. This, of course,

would place the base of the Whitehorse approximately near the top of the Queen sand series.)

(Correlations of the Apache limestone with the Delaware sandstone are incorrect, as the Apache limestone contains the same species of *Polydiexodina* as are found on the very top of El Capitan. Specifically these forms are not found in the lower dark limestone of the Delaware sandstone.)

(It is to be noted that the San Andreas does not vary greatly in lithology from the Bone Springs. Where observed in Last Chance and Sitting Bull canyons, immediately north of the Guadalupe Mountains, it bears no resemblance to the Delaware sandstone above the Bone Springs limestone. The Carlsbad formation is represented in the section of Capitan limestone found above Pine Springs Canyon in the Guadalupe Mountains.) Blanchard and Davis correlate the Carlsbad limestone with dolomites, anhydrites, and red beds which are commonly referred to as Castile; that is, the Castile gypsum is supposed to be made up of the Carlsbad and younger beds of gypsum and red beds, and is supposed to lie conformably on the Delaware sandstone series. The Rustler dolomite traced eastward lies above the upper salt series. (The writer is of the opinion that the unconformity at the base of the Custer is present well above the Queen sand zone and that the underlying Capitan limestone and Delaware sandstone occurs as a wedge separating the Castile from the underlying Bone Springs. The Upper Leonard may be carried by partial paleontological evidence into the Blaine and Dog Creek.)

Willis[1] gives a very complete report on the whole Permian situation of west Texas, establishing many correlations and bringing in no new names. Considerable stress is placed on the unconformity at the base of the Whitehorse; no mention, however, is made of a considerable time-break. Note is made of a lateral transition of the Alibates dolomite into the Cloud Chief in the Panhandle of Texas; this is especially so around structure, and the same holds for Oklahoma. In this paper all of the beds above the San Andreas, that is, the red shale, sandstone, and gypsum, called the "Seven Rivers gypsum," is correlated with the Whitehorse, Cloud Chief, and Quartermaster.

[1] R. Willis, "Preliminary Correlation of the Texas and New Mexico Permian," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIII, No. 8 (August, 1929).

From a lithologic standpoint the red sand in the Artesia and Maljamar districts is a part of the Custer. In correlating the Rustler and Castile from west to east, Willis gives two possible explanations; the whole of the Rustler or salt series may be equivalent to Cloud Chief, or the salt may be a lens below the Cloud Chief which wedges out eastward with an unconformity at the base of the overlying red beds which would remove the Rustler. Mention is made of the radical change of deposition which occurs between the Frijole limestone and Castile, though no unconformity was recognized. The top of the Queen sand is correlated with the red sand, already mentioned as a marker in the Artesia and Maljamar districts. (This would make the Queen sand and Carlsbad limestone equivalent to the Custer in part. The Queen sandstone at Queen post-office is a part of the Delaware Mountain formation and is in no way equivalent to the Whitehorse.) Mention is made of the gradation of the Carlsbad limestone into anhydrites and red beds north of Carlsbad. Many believe the anomaly of marine sediments being laid down next to beds of anhydrite and salt is accounted for by local occurrence of a regional reef, the Capitan of the Delaware Mountain formation serving as a barrier reef. (If a younger age is given these beds of desiccation, no such peculiar phenomenon is necessary.) In the Glass Mountains, Willis wishes to correlate the Whitehorse with the Gilliam, the Tessey being equivalent to Castile and Rustler. (However, the *Fusulininae* show the Tessey and Gilliam to belong in the Delaware Mountain formation and not with the Custer.)

Adams[1] has given a very good paper on the Triassic of west Texas, dividing the Triassic or Dockum series into the Santa Rosa and Chinle. He does not mention the possibility of Moenkopie equivalents.

Clifton[2] presents a very complete paper dealing with a local phase of the general problem in Oklahoma. While no new formation names are proposed, Clifton recognized the great need of a revision of the formations now used. He wishes to include all beds from the Day

[1] J. E. Adams, "Triassic of West Texas," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIII, No. 8 (August, 1929).

[2] R. L. Clifton, "Permian Structure and Stratigraphy of Northwestern Oklahoma and Adjacent Areas," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIV, No. 2 (February, 1930).

Creek dolomite up to and including the red beds above the Big Basin sandstone in the Cloud Chief formation. The Whitehorse is recognized as a series of depositional units rather than an easily distinguished formation, mentioning that it contains gypsums, dolomites, etc., which grade laterally into each other, thus making it extremely difficult to differentiate Whitehorse and Cloud Chief, especially as the Day Creek is known to grade laterally into gypsum. Speaking of gypsums in Beaver County, Clifton regards them as being at the top of the Whitehorse and associated with the Day Creek. In regard to the channel deposits which are so widely distributed and associated with the Whitehorse, Clifton believes them to occur well up in the Whitehorse. (The writer disagrees with this, as the material below these channel deposits does not carry Custer lithology.) The Hackberry shale is perpetuated. As to the Big Basin sandstone, mention is made of the presence of white bands which are reported to be characteristic of the Quartermaster. Clifton, however, wishes to put the Big Basin into the Cloud Chief which underlies the Quartermaster.

Cartwright[1] makes some interesting statements about the change in color from orange to gray over the top of structures of Whitehorse sandstone, citing the Chalk-Roberts field. (It has been noted in other fields, such as the Cement field in Oklahoma.) The Whitehorse–Cloud Chief lithology is described as being identical with the Yates sand of Yates Pool, Texas, and is carried into the top of the Queen sand zone by correlation. The Castile is divided into two evaporite formations, the lower of which consists of gypsum and dolomitic gypsum, some gray shale, and potash-poor salt; the upper is described as massive gypsum and anhydrite with potash-rich salt. It is suggested that an unconformity is present between the Castile and Rustler.

Patton,[2] in his paper on Stonewall County, Texas, originates a new name, the "Peacock formation," which is defined as including all beds from the Blaine (as used in Texas) to the base of the Triassic or Dockum beds. No recognition is made of Custer equivalents, though, of course, they are present.

[1] L. D. Cartwright, "Transverse Section of Permian Basin, West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIV, No. 8 (August, 1930).

[2] L. T. Patton, "The Geology of Stonewall County, Texas," *Bull. Univ. Tex., No. 3027* (July, 1930).

Evans[1] describes the geology of northwestern Oklahoma and makes some unusual correlations. In this article we have the interesting inversion of the Cloud Chief and Day Creek dolomite. The Whitehorse formation is divided into three members: at the base the Marlow member containing the Relay Creek dolomites, proposed for the preoccupied Greenfield limestone; the Rush Springs, or middle member, containing the Weatherford dolomite (one member of the Weatherford was previously called Day Creek by Evans); and the top member, the Cloud Chief. Above the Whitehorse formation is the Day Creek dolomite, above that, the Quartermaster formation, proposed to include the Hackberry and Big Basin sandstone, which Evans suggests dropping. The Rush Springs member is the Whitehorse as used by most geologists. Evans does not recognize an unconformity at the base of the Whitehorse.

This paper foreshadows difficulties in the future, i.e., the Whitehorse will be extended upward and as time goes on may be extended to include the Quartermaster. Such interpretations cannot help but be evolved, due to the similarity of the sediments from top to bottom. If the names "Quartermaster," "Cloud Chief," and "Whitehorse" are to be retained, it should be as zones or members of a larger and more easily defined formation.

Figure 1 shows the writer's conception of the correlations based upon unconformities of regional magnitude. There is some doubt as to the equivalents of the standard world series and the North American Permian.

REGIONAL DISTRIBUTION

The Custer, as such, may be carried on the outcrop and beneath the surface farther than any other series of beds found in the red beds of the mid-Continent. Starting in Kansas, the Custer beds first appear from beneath the Comanchean overlap in southeastern Kiowa County. It may be followed southward across Oklahoma and into Texas where in Cook County it is again overlapped by the Comanchean. In the southern Texas counties it is a part of the Double Mountain formation and is not well marked off above and below, except by a change in lithology. From a subsurface standpoint, it

[1] N. Evans, "Stratigraphy of Permian Beds in Northwestern Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XV, No. 4 (April, 1931).

CORRELATION CHART

	STANDARD WORLD GEOLOGIC SERIES	GRAND CANYON SERIES	GLASS MOUNTAIN SERIES	GUADALUPE MOUNTAIN SERIES	SOUTHEAST NEW MEXICO	CENTRAL NORTHERN TEXAS	OKLAHOMA & KANSAS	NORTH EAST -ERN COLORADO	SOUTH DAKOTA	WYOMING	SOUTH EAST -ERN IDAHO
TRIASSIC	KEUPER	CHINLE / SHINARUMP		CHINLE / SANTA ROSA SANDSTONE	Dockum: CHINLE / SANTA ROSA	DOCKUM (TRUJILLO (TECOVAS) Panhandle of Texas) / CAMP SPRINGS CONGLOMERATE	DOCKUM IN PART (CIMARRON CO. OKLA.)	JELM	JELM VERY LOCAL	UPPER CHUGWATER / POPO AGIE	WOOD / DEADMAN / SIGHAM / ANKAREH
	MUSCHELKALK										
	BUNTER	MOENKOPIE		RED BEDS RUSTLER CASTILE	UPPER RED BEDS SALT AND ANHYDRITE IN PECOS VALLEY	Woodward: CUSTER FORMATION / CHANNEL SANDSTONE LOCAL AT BASE	CUSTER FORMATION / VERDEN CHANNEL SAND-STONE	ALCOVA & LOWER RED BEDS / LYKINS / FORELLE / SATANKA	SPEARFISH / MINNEKAHTA / OPECHE	CHUGWATER / FORELLE / SATANKA	TIMOTHY / THAYNES / WOODSIDE
PERMIAN	THURINGIAN		TESSEY / GILLIAM / VIDRIO / WORD	Delaware Mountain Formation: CAPITAN LIMESTONE / DELAWARE SAND-STONE							
	SAXONIAN	KIABAB PRODUCTUS WESI / COCONINO / ? HERMIT	LEONARD / HESS = BASAL CONGLOMERATE	BONE SPRINGS LIMESTONE	CHUPADERA: SAN ANDRES PRODUCTUS WESI? / GLORIETA SAND-STONE	Abo: Cedar Canyon, Quitaque, Lower Clear Fork, San Angelo / CLEAR FORK	DOG CREEK TO WELLINGTON	LYONS			PHOSPHORIA
	ARTINSKIAN "SCHWAGERINA ZONE."		WOLFCAMP "SCHWAGERINA ZONE."		SCHWAGERINA ZONE 400' ABOVE BASE OF YESO (AFTER KEYTE) / ABO	WICHITA / CRYSTAL FALLS LIMESTONE "SCHWAGERINA ZONE"	MARION TO NEVA "SCHWAGERINA ZONE"				

FIG. 1

may roughly be traced across Kansas running through Pratt, Stafford, Barton, Ellsworth, Russell and Osborne counties, after which locality it takes a decided west swing across Smith and Phillips counties and into Nebraska. The well in T. 1 N., R. 13 W., in Nebraska, shows no Custer, and pre-Dakota erosion has progressed well into the Wellington formation.

The trace of the base of the Custer formation as detailed in Kansas, Oklahoma, and east side of the Permian basin of west Texas is shown in Figure 2.

REGIONAL CORRELATIONS

It is not difficult to find lithological equivalents of the Custer formation on the outcrop, from the Black Hills south along the eastern face of the front range of the Rocky Mountains into New Mexico and Texas. Starting in the north, probably the closest equivalent lithologically is the Spearfish formation of the Black Hills; in fact, the resemblance is so startling that there can be but little doubt of the equivalence. The Black Hills section consists at the base of the Opeche formation which is a very bright vermilion red shale. It has been placed questionably in the Permian, due to fossils that are found in the overlying Minnekahta. The Minnekahta limestone is in reality a dolomite, and its environment is undoubtedly similar to that of the Day Creek dolomite. Samples of one look exactly like the other, being very finely bedded, and taken as a whole the color is pink. Fossils of the Minnekahta have long been regarded as indicating probable Permian age, but growth of knowledge as to their identity and significance has made this classification extremely uncertain. Girty[1] has re-examined the fossils of the Minnekahta subsequent to the work done in Wyoming and makes the following statement:

> These fossils are too few and too imperfect to prove the age of the Minnekahta limestone. If the area is regarded as belonging to the basin of the Mississippi they might be classed as Permian but they have so much in common with the Triassic of basins that lie farther west that they more probably belong to that period.

[1] N. H. Darton and S. Paige, *Central Black Hills Folio, No. 219, U.S. Geol. Surv.* (1925).

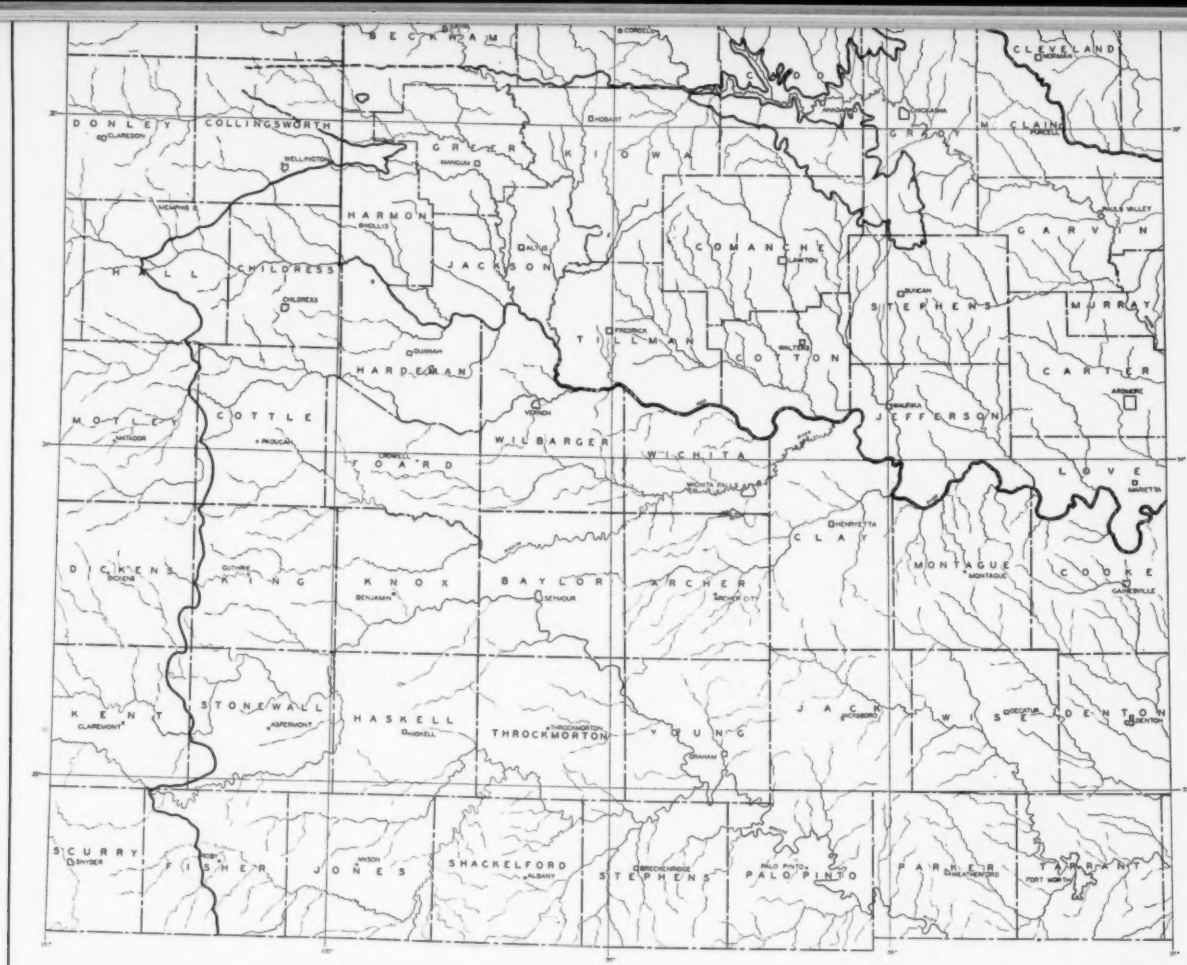
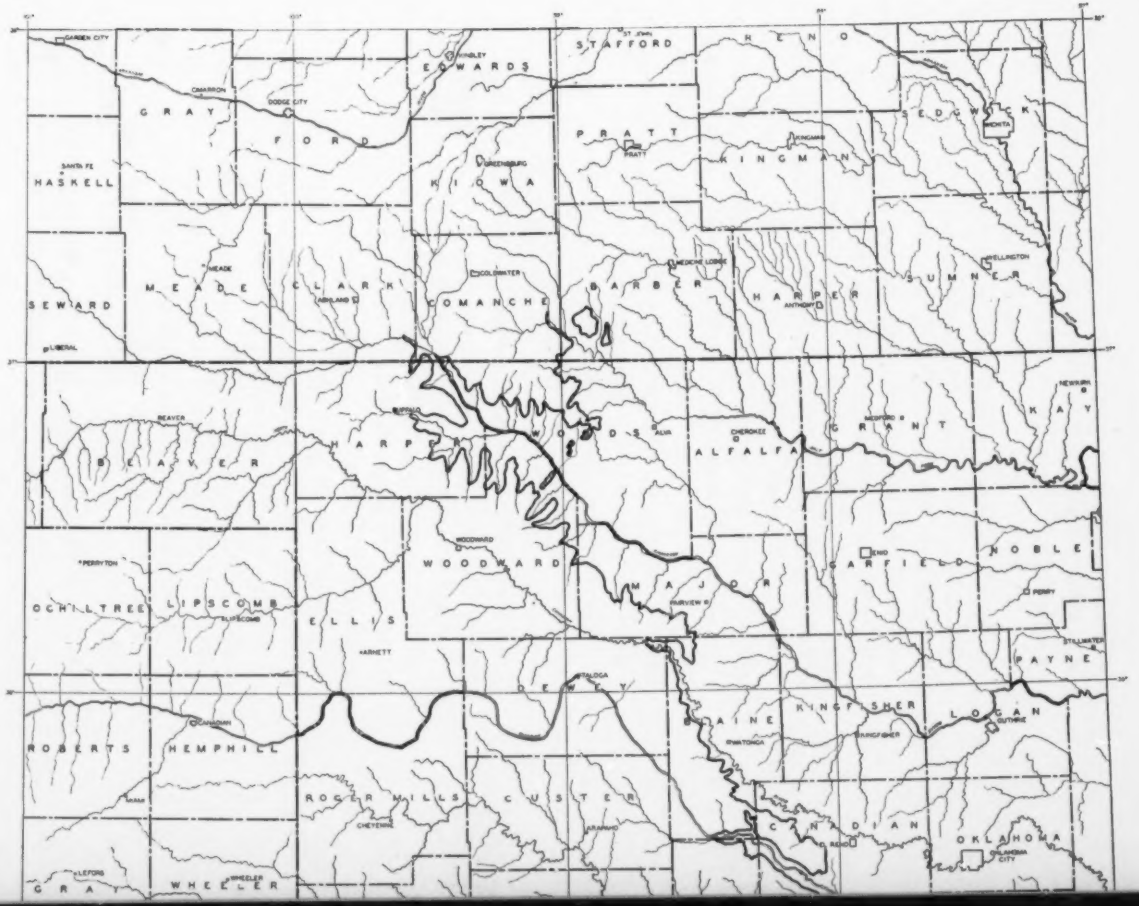

DONLEY
COLLINGSWORTH
GRAY
WHEELER
HEMPHILL
HARMON
GREER
KIOWA
CLEVELAND
MCLAIN
GARVIN
HALL
CHILDRESS
JACKSON
COMANCHE
STEPHENS
MURRAY
TILLMAN
COTTON
CARTER
HARDEMAN
MOTLEY
COTTLE
FOARD
WILBARGER
WICHITA
JEFFERSON
LOVE
CLAY
DICKENS
KING
KNOX
BAYLOR
ARCHER
MONTAGUE
COOKE
KENT
STONEWALL
HASKELL
THROCKMORTON
YOUNG
JACK
WISE
DENTON
SCURRY
FISHER
JONES
SHACKELFORD
STEPHENS
PALO PINTO
PARKER
TARRANT

FIG. 2

FIG. 2


GARDEN CITY
KEARNEY
EDWARDS
STAFFORD
RENO
GRAY
FORD
DODGE CITY
CIMARRON
PRATT
KINGMAN
SEDGWICK
WICHITA
SANTA FE
HASKELL
GREENSBURG
KIOWA
MEADE
CLARK
COLDWATER
COMANCHE
BARBER
HARPER
SUMNER
SEWARD
LIBERAL
BEAVER
HARPER
WOODS
ALFALFA
GRANT
KAY
WOODWARD
GARFIELD
NOBLE
PERRYTON
OCHILTREE
LIPSCOMB
ELLIS
MAJOR
PERRY
PAYNE
ROBERTS
HEMPHILL
BLAINE
KINGFISHER
LOGAN
ROGER MILLS
CUSTER
CANADIAN
OKLAHOMA
OKLAHOMA CITY
LEFORS
WHEELER
GRAY

The problem at hand is not so much concerned with the Opeche and Minnekahta as it is with the Spearfish. The foregoing notes were added to indicate the strong Triassic facies of that which was thought at one time to be Permian.

The Spearfish is correlated with the Lower Chugwater formation, the Upper Chugwater contains beds distinguished by the name Popo Agie. The Popo Agie beds contain Triassic vertebrates which were discovered by Brown, and the forms found were *Dolichobrachium gracile*, *Eubrachiosaurus browni*, *Brachybrachium brevipes*, and *Paleorbunus bransoni*. Williston[1] states concerning these beds: "I am much inclined to believe that the Pope Agie beds, which may be contemporaneous with those yielding vertebrate fossils in Utah, Arizona, New Mexico, and Texas, are of early Keuper age, while the Connecticut Valley, Red Mountain, and Hallopus beds of southern Colorado are later in time."

As the lithology of the Upper and Lower Chugwater are identical and as the Lower Chugwater is identical in lithology with the Spearfish, the writer believes that he is not overstepping the bounds of reason in making them equivalent. In running the Spearfish into the Custer there is little difficulty involved, as deep wells across southwestern Nebraska and western Kansas have penetrated rocks of Spearfish age which in turn may be run into the Custer, though the Minnekahta and Opeche become lost en route. A pronounced unconformity is always noted at the base of these beds, and it is impossible for the Spearfish to run into the Permian red beds below unless the lithology completely changes, which would necessitate a change in environment which is not the case. In dealing with the Satanka, Forelle, Lykins, and Jelm, probably the best reference is *Professional Paper No. 149*.[2] The Satanka shale and Forelle limestone are undoubtedly equivalent to the Opeche and Minnekahta; they are similar in lithology, and the Forelle limestone has yielded essentially the same genera that were found in the Minnekahta. No fossils have been found in the Lyons sandstone except tracks of reptiles which were called Permian by Gilmore in a personal com-

[1] S. W. Williston, "The Hallopus, Baptanodon, and Atlantosaurus Beds of Marsh," *Jour. Geol.*, Vol. XIII (1905), pp. 339–40.

[2] Pp. 10–15

munication to Lee. They were compared with fossil footprints from the Coconino sandstone of the Grand Canyon in Arizona, a formation classed as Permian. Gilmore says: "I find that the affinities of this species (*Linnopus? coloradoensis*) fall in the genus *Laoporous* which is described from the Coconino sandstone," and after describing the genus and species Gilmore again states that "from the brief review given above it becomes quite apparent that so far as the rather meager evidence of these footprints is concerned it would point to a similar age of these two widely separate sandstones." The writer has seen both sandstones in the field and believes that this correlation is correct. The overlying Chugwater formation contains the Alcova limestone from which the following fossils have been found: *Naticalelia* sp., *Bakewellia* sp., *Pleurophorus?* sp., and *Aviculipecten* cf. *A. curticardinalis*. Although the above fossils are inadequate for final determination of age, they do indicate that the limestone is of marine origin and since the only marine Triassic sediments near central Wyoming are recognized as Lower Triassic, it is probable that the Alcova limestone should also be classed as Lower Triassic.

The closest lithologic affinities of the Custer are to be found in the region immediately west of Oklahoma in New Mexico; the outcrops are closer together and the lithologic sequence can be carried to a greater nicety. Going eastward down the Dry Cimarron Canyon in Union County, New Mexico, beds which contain Triassic vertebrates may be traced eastward on the outcrop directly into Cimarron County, T. 5 N., R. 6 East Cimarron meridian, Oklahoma. Carrying this lithology northward, the Dockum and the underlying Custer attain an enormous thickness in the borings of Bent and Baca counties, Colorado. Carrying the Custer lithology eastward across the Panhandle of Oklahoma, that is, through Texas and Beaver counties, well-log comparisons show that it extends into Harper and other counties of western Oklahoma. A little farther south in New Mexico there are a number of wells in Quay County which clearly show the relationships of the Chinle and Santa Rosa to the underlying salt and anhydrite series. This series may be carried into Lea County, New Mexico, in the general vicinity of Roswell. Also the anhydrites and salt series which have Custer lithology may be

traced laterally into the Castile and Rustler. Concerning the red beds which overlie the Rustler, their lithology is indistinguishable from that of the red beds found in the Chinle and interbedded with the Santa Rosa sandstone and would be called the same were it not for the unconformity at the base of the Santa Rosa. These shales contain grits and are very micaceous in places, the general color being a bright orange red.

Thus the eolian, highly polished sand grains found in the Custer are lithologically identical with the Spearfish sands, and the same type of sands are to be found interbedded with the Castile and Rustler. The shaly phase in the upper part of the Custer, called Quartermaster, etc., by Gould, is identical with red beds overlying the Rustler and with the red beds overlying the unconformity at the base of the Santa Rosa.

UNCONFORMITIES

In tracing the Custer across Kansas, Oklahoma, and Texas, on the surface there is little evidence suggesting a pronounced unconformity. There are, however, certain instances which show that an unconformity exists aside from the marked lithologic change. For instance, in Barber County, Sec. 18, T. 30 S., and R. 15 W., Kansas, there is a good exposure of the contact between the Dog Creek shale and the overlying Custer which shows an angular contact between the Dog Creek and Whitehorse. Farther south in Oklahoma there are one or two instances which show the unconformity to better advantage. Near Wildcat Mounds in Woods County, the complete removal of Dog Creek and Blaine formations prior to Custer deposition may be observed. At the southeast end of the Anadarko Basin, that is, in Grady, Stephens, and Comanche counties, it is strongly suggested that the Dog Creek and Blaine formations are nonexistent due to overlap. Further evidence of this overlap is shown by the dolomites at the base of the Blaine which continue much farther south after the Blaine gypsum is cut out. The Marlow looks exactly like the Flower-Pot which underlies the Blaine. In Texas the evidence is not so good as might be expected; however, on the south flank of the Panhandle arch in northern Childress County, the Custer may be observed lying directly on beds well below the top of the Blaine. The Aspermont dolomite (the uppermost member of the

Blaine as used in Texas) and part of the section below it, are missing. In central Cottle County the Custer rests directly upon the Aspermont. In the Rocky Arroyo of the Guadalupe Mountains the Seven Rivers gypsum rests unconformably upon the Delaware Mountain formation.

In well samples, however, the unconformity is much more pronounced; this is especially so as the wells approach the Rocky Mountains. In carrying the Custer across southwestern Kansas into southeastern Colorado, it is found to rest upon beds of Dog Creek age down to limestones of Cambrian age, and doubtless the pre-Cambrian was exposed in many places. In carrying the Custer toward the northwest, the same conditions are found where the Spearfish may be shown to rest upon a great many different formations.

Across the basin of west Texas the unconformity at the base of the Custer is not very apparent, due largely to lack of pronounced local deformation. In general, however, the conditions are the reverse from those found going from western Kansas toward the Rocky Mountains; that is, the older Permian beds are exposed on the eastern rim of the basin, whereas along the western side of the basin the youngest Permian found in North America crops out in the mountains called Delaware and Guadalupe, as well as in a number of the other local uplifts. In wells, the Custer equivalents rest upon lower Double Mountain along the eastern side of the basin. The younger Permian sediments or Delaware Mountain formation feather out somewhere along the eastern side of Reagan County and possibly extend into Irion County. This line cannot be definitely determined as yet. Cores have been taken of the Texon pay found in the Big Lake oil field containing several species of the genus *Polydiexodina* which are conspecific with those collected by the writer from the summit of El Capitan, and from the Apache limestone, thus proving the equivalence of these beds and establishing the base of the Custer as below the anhydrites which immediately overlie the Texon pay. The writer believes that this unconformity is below the brown limestone and in the white limestone as used in the oil fields to the west of the Big Lake area. Conglomerates have been cored in the Hobbs area, New Mexico, which are from this horizon. As these horizons are quite widespread, further local detail is not necessary. By compari-

son with Texas, the time interval separating the Custer from the underlying red beds in Kansas and Oklahoma has quite a duration. Over a very broad area this interval, represented by the unconformity, marks the absence of the upper part of the Permian called Thuringian.

PALEONTOLOGIC EVIDENCE

The sediments below the Dockum beds are practically non-fossiliferous, except the channel sandstone at the base. The occurrence of fossils in this horizon is most unusual in view of the fact that the fossils are supposed to be marine. The fossils which occur in the channel sandstone at the base of the Custer are largely in a very poor state of preservation. The channels are composed of conglomerates both coarse and fine. The pebbles are from the underlying shales and sandstones and range from the size of a pea up to 2 feet in diameter. These pebbles and boulders are cemented by a matrix of calcareous dolomite and typically eolian Custer sandstone. Some of the cementing material is calcite. An excellent place to see these large conglomerates is at Channel Buttes, 12 miles northwest of the Cimarron River bridge southwest of Waynoka, Oklahoma.

Conglomerate pebbles of this size must have required streams of considerable velocity which probably acted only through a temporary period, as the channel deposits are not very thick. The velocity of the water moving these pebbles would be much above that of any current moving along the sea bottom. As a result, the water, which carried the sediments, at best could not have been more than of brackish nature. This would tend to kill or greatly change any marine life that happened to enter these waters. An example of brackish water adjacent to marine water may be studied in the Puget Sound region of the State of Washington, and the enclosed life shows a very considerable variation from the typically marine water toward the ocean.

The channel deposits are the only beds of the Custer in which fossils have been found up to the present time, and it seems highly improbable that a correlation between them and typically marine fossils could be made. Figure 3, which is a list of all the fossils described to date from the channel sandstones, is compiled from the work of Beede and Clifton, the localities being all from Oklahoma except

FAUNA OF CHANNEL SANDSTONES								
CLASS AND SPECIES	LOCALITIES							
	Whitehorse Springs	Dozier Mounds Texas	Doe Creek Mounds	Verden	Woodward	Cleveland Hills	Wildcat Mounds	
CHAETOPODA								
Serpula ?		X						
Spirorbis sp.	X							
BRYOZOA								
Stenopora sp.	X	X	X					
BRACHIOPODA								
Chonetes ?			X					
Dielasma schucherti, Beede	X	X	X	X				
PELECYPODA								
Allorisma ? albequus, Beede	X	X						
Astartella sp.	X	X						
Aviculopecten occidentalis ? Shumard	X	X	X	?			X	
Aviculopecten oklahomaensis, Beede	X	X						
Aviculopecten vanvleeti, Beede	X	X	X					
Bakewellia gouldi, Beede	X	X	X	X	X	X	X	
Bakewellia parallelidentata, Beede	X	X	X	X	X	X	X	
Conocardium oklahomaensis, Beede	X		X					
Cyrtodontarca gouldi, Beede	X	X						
Cyrtodontarca multidentata, Beede	X	X						
Cyrtodontarca parallelidentata, Beede	X	X						
Edmondia cumminsi, Beede	X	X						
Edmondia rotunda, Beede	X	X	X					
Limoptera sp.	X	X	X	X	X		X	
Myalina permiana, Swallow	X	X						
Pleurophorus ? albequus ? Beede	X	X	X	?	X	X	X	
Pleurophorus albequus Longus, Beede	X	X	X					
Pleurophorus whitehorsensis, Clifton	X							
Pseudomonotis sp.	X							
Schizodus oklahomaensis, Beede	X							
Schizodus ovatus, Meek & Hayden ?	X	X	X	X				
Sedgwickia sp.	X							
Solenomya whitehorsensis, Clifton	X							
GASTROPODA								
Bulimorpha ? alvaensis, Beede	X							
Capulus sp.	X							
Capulus ? haworthi, Beede		X						
Capulus sellardsi, Beede	X	X	X					
Loxonema permiana, Beede		X						
Murchisonia collingsworthensis, Beede		X						
Murchisonia gouldi, Beede	X	X	X	X	X	X	X	
Naticella transversa, Beebe	X	X	X					
Orthonema sp.	X	X	X	?	X			
Orthonema doziarensis, Beede		X						
Orthonema texana, Beede	X	X						
Plagioglypta ? sp.		X						
Pleurotomaria agnostica, Beede	X							
Pleurotomaria capertoni, Beede	X	X	X	X	X			
Pleurotomaria depressa, Beede	X		X					
Strophostylus permianus, Beede	X	X	X	X	X	X	X	
Trepospira haworthi, Beede	X	X						
Worthenopsis depressa, Beede	X							

FIG. 3

Dozier Mounds, which is in Texas. Biologically the whole assemblage, that is, the tremendous development of pelecypods and gastropods to the practical exclusion of all other forms, resembles a Triassic fauna. The brachiopods are represented by two genera, *Dielasma* and *Chonetes*. The genus *Chonetes* was identified from a single fragment and is of questionable relationship. This leaves the one genus, *Dielasma*, and it occurs both in the Triassic and the Carboniferous. In the list of thirty genera there are but three species which are not new, and two of these species are questioned. All the other species are new and have not been described elsewhere. Of the thirty genera, eighteen of them are known to occur in the Triassic, and twelve have not been listed above the Permian, although some formations which are now, and have been, classed as Permian may prove in the future to be Triassic. One notable example familiar to many is the Moenkopie, which up until very recently was considered to be of Permian age. Of the gastropods, one genus, *Naticella*, is not known to occur anywhere below the Triassic. There are, on the other hand, such forms as *Aviculopecten occidentalis*, Shumard, which, though questioned specifically in the accompanying list, is known to be present in the Triassic. Similarly, *Myalina permiana*, Swallow, is also known to occur in the Triassic. Girty has mentioned, in discussing the fossils found in the Minnekahta limestone, the fact that several pelecypods called *Schizodus* later turned out to be the Triassic genus *Myophoria*, and it is not improbable, considering the generally poor state of the preservation, that such may be the case with the *Schizodus* listed. The fact should not be overlooked that all of the species are new except three which are questioned. The determination of age will depend upon the trading of one genus against another, depending upon their described geologic range in the literature, which is far from complete. From the peculiar mode of occurrence it is very probable that a careful study of the fauna which has been collected will bring many things to light that were previously overlooked.

PETROLOGY

Of all the formations found in the mid-Continent red beds there is none so distinct as the Custer sandstones. Everyone who has worked upon these sandstones in the field will agree that little like them is

found below the base of the Custer, which is even more distinctive regionally speaking than the widely distributed Blaine formation. Its fantastic types of weathering and brilliant vermilion coloring are even more marked after a rain, standing out with startling vividness. It is largely composed of sand in the northern facies, especially in Kansas, but toward the south the percentage of dolomite and anhydrite increases markedly, locally developing beds of dolomite, as, for instance, the two dolomite beds west of Greenfield, Oklahoma. These dolomites resemble greatly the Day Creek dolomite, being finely banded and many of the bands pink in color.

The sands of the Custer are for the most part rather fine, though in some places they are as coarse as any of the sands found in the underlying Permian. The bright coloring of the individual sand grains found in the Custer is extremely persistent, being present even after boiling with dilute hydrochloric acid; strong boiling with concentrated acid will, of course, clear up the grains. This coloring is put upon the grains in the form of a polish and under the microscope is most distinctive. It is believed to be primary rather than secondary for the following reasons: Custer sand grains are commonly found cemented by anhydrite and dolomite which maintain their full coloration. They are also found imbedded in dolomites, still with the same bright coloration. These grains are not as beds, but as individual grains. Custer sands are highly polished and subangular, none of them being really angular. They are not frosted, except for a few grains which are all rounded apparently from an older generation. Figure 4, Custer sandstone collected from the center North Line, NE. $\frac{1}{4}$ of NE $\frac{1}{4}$, Sec. 25, T. 25 N., R. 12 W., Oklahoma, from a horizon about 10 feet below the upper dolomite. It will be seen by careful study that the Custer sand grains though well rounded tend to be rather flat. Probably under further action by wind and water the grains will lose this flat character. Figure 5, St. Peter sandstone, is for comparison and was taken from Pike's Peak Road $1\frac{1}{2}$ miles south of McGregor, Iowa, Sec. 34, T. 94 N., R. 2 W. An examination of this figure will show, outside of some of the few small angular grains, that the larger ones are very well rounded and frosted, which is very distinctive both on the outcrop and in well samples. Under high magnification, the St. Peter grains show that the frosting really is due

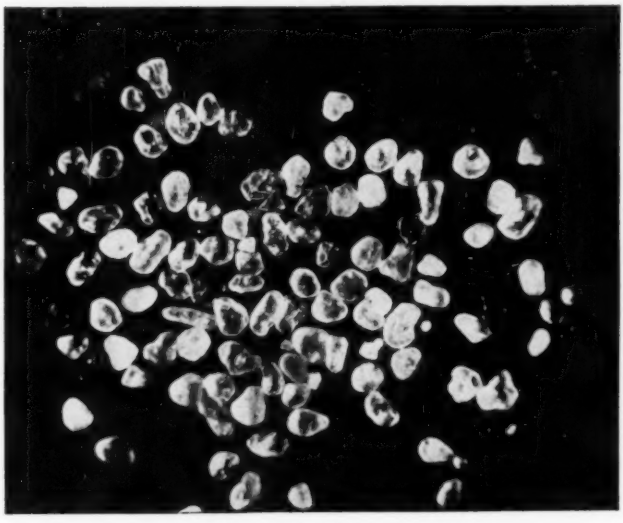


FIG. 4.—×10

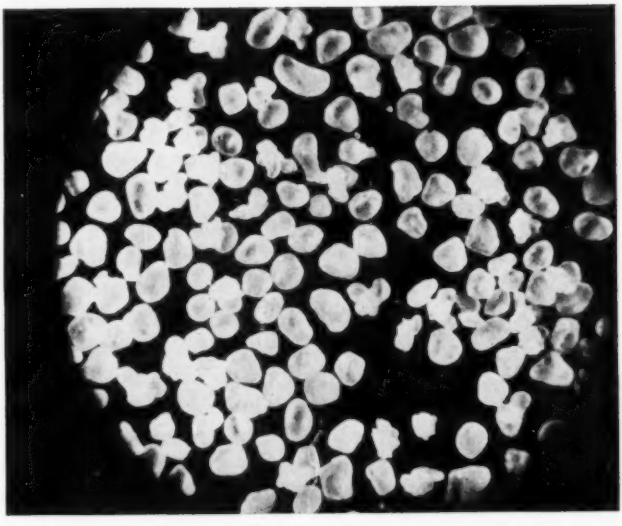


FIG. 5.—×10

to a secondary enlargement by percolating waters containing dissolved silica. This secondary enlargement is in the form of minute crystal facets starting to form a complete crystal of quartz out of the individual sand grain. It is in no sense a drusy character involving individual crystals, but in reality one crystal developing a great number of facets upon its face. This is quite characteristic of large quartz crystals which upon examination will show this stair-step effect. Probably the sand grains from the St. Peter were at one time as highly polished as those found in the Custer, but through greater age they have assumed this appearance which was thought by many to be due to abrasion. Some of the grains in the Custer are feldspars, chiefly microline, etc., which are well rounded and milky colored but definitely show cleavage in certain faces. They show as some of the milky grains in Figure 4.

Associated with the base of the Custer is frequently a very fine conglomerate composed of well-worn small pebbles of chert of various sorts, of which the degree of rounding is quite distinctive. These fine conglomerates are commonly associated with the channel sandstones and may be observed to advantage in the SW. $\frac{1}{4}$ of SW. $\frac{1}{4}$ of SW. $\frac{1}{4}$, Sec. 18, T. 4 N., R. 6 W., Grady County, Oklahoma. A different type of fine conglomerate is associated with that which has been called the Quartermaster, and is composed chiefly of very large well-rounded quartz grains imbedded in a much finer sandstone matrix. This type of material is well exposed in the NW. $\frac{1}{4}$ of NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$, Sec. 5, T. 11 N., R. 23 W., and also in the SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, Sec. 28, T. 13 N., R. 23 W., Roger Mills County, Oklahoma.

The anhydrites and dolomites of the Custer are also quite distinct from those occurring in the underlying Permian. The dolomites are often sandy and usually contain thin beds of reddish material, giving the dolomite a crinkly aspect. It is almost always coarsely crystalline to sucrose in texture. Much chert is associated with these dolomites in certain areas. The anhydrites appear to be rather thin bedded, the beds separated by thin layers of reddish material and sucrose in texture. Massive ledges in the Custer are practically nonexistent, in contradistinction to the Blaine formation.

The shales are usually of vermilion red color, though considerable variation may be noted from place to place. They are very mica-

ceous in places, but in the majority of cases not more so than the underlying Permian shales. The presence of phosphates is considered to be diagnostic of Triassic sediments by many workers in Texas, but in the writer's opinion this is not a valid method of differentiating the Permian from the Triassic. Many samples have been analyzed which show no phosphate present; even conglomerates which carry Triassic vertebrates in Union County, New Mexico, have been analyzed with the same results. Phosphate from the Comanchean probably contaminated the well samples which were analyzed in west Texas.

A peculiar shale occurs in the SW. $\frac{1}{4}$ of SW $\frac{1}{4}$ of SE. $\frac{1}{4}$, Sec. 5, T. 11 N., R. 23 W., Roger Mills County, Oklahoma. It is an extremely fine gray shale, probably derived from an altered volcanic ash; its occurrence would be hard to explain otherwise, as it is overlain and underlain by windblown sands characteristic of the formation. There are many other unique phases of lithology found in these sediments which in many cases have led workers in the field to publish a bewildering number of names that may be applied only in very local areas.

Triassic salt, which is very abundant in west Texas, is characterized by the presence of potash salts which are absent in the Permian salts.

PETROGRAPHY

Both the light and heavy minerals found in the Custer are markedly different from any found in the underlying Permian sandstones. This is best shown by Figure 6, which is the revised compilation of the charts prepared by Spencer.[1]

A study of the chart shows interesting things. It is to be seen that leucoxene shows a marked decrease in the Custer when compared to the underlying sandstones. Ilmenite, on the other hand, shows a rather marked increase. This is to be expected when two sandstones are separated by a pronounced time-break, whether systemic or not.

Milner[2] has made extensive studies of the alteration of ilmenite to

[1] M. F. Spencer, *Petrographic Description of the Whitehorse and Other Permian and Pennsylvanian Sandstones of Oklahoma*, unpublished thesis at the Univ. Okla., 1930.

[2] H. B. Milner, *Supplement to an Introduction to Sedimentary Petrography*. London: Thomas Murby & Co., 1926.

leucoxene, the results of which are quoted:[1] "The ilmenite-leucoxene ratio alters in favour of the latter with increasing geological age of the enclosing sediment." Furthermore,[2] "Ilmenite tends to alter to leucoxene under hydrous conditions, but the latter may be both detrital and authigenic."

PETROGRAPHIC ANALYSIS OF THE WHITEHORSE & PERMIAN SANDSTONES

Minerals	Percentage in Various Sandstones				
	Wellington	Garber	Hennessey	Duncan	Whitehorse
Leucoxene	63.7	58.0	72.1	68.8	39.9
Ilmenite	16.7	10.1	5.1	4.7	17.6
Zircon	9.9	18.8	8.4	10.9	12.1
Rutile	2.0	3.3	0.2	1.9	1.8
Tourmaline	4.8	7.6	8.0	10.1	17.5
Garnet		0.3	0.2	0.6	3.6
Staurolite	2.1	0.5	2.2	1.2	3.0
Epidote					0.4
Hornblende					0.02
Mica	0.6	0.4	3.6	0.1	3.3
Felspar	20.0	15.8	14.0	15.3	23.2

MECHANICAL ANALYSIS

Sieve	Percentage in Various Sandstones				
+100-mesh	31.5	23.0	0.9	15.9	14.1
+200-mesh	50.0	55.9	20.9	58.9	55.8
-200-mesh	18.4	21.0	77.1	25.0	29.5

FIG. 6

In looking at the table it can readily be seen, starting with the Wellington, that the ratio of ilmenite to leucoxene is 1–4, Garber 1–5, Hennessey 1–14, Dunkin 1–17, and Whitehorse 1–2. Another possible explanation for the marked change in ratio found in the Custer may be due to the fact that it is largely composed of eolian sand. In the process of attrition the leucoxene may have been removed from the ilmenite and of necessity be finely ground and lost. This postulates no further alteration after deposition. In any event, however, the increase in ilmenite is an important factor.

Considering the hydrous condition suggested by Milner, it may be stated that the Custer is quite pervious, and meteoric waters will have free circulation throughout the sandstone. The underlying Permian sandstones are separated by more or less impervious shales. This would tend to increase the ratio of leucoxene to ilmenite in the Custer, which is not the case.

Zircon and rutile show practically no change between the White-

[1] *Ibid.*, p. 110. [2] Personal communication.

horse and the underlying sandstones. Tourmaline, garnet, and staurolite show rather pronounced increases in the Whitehorse, being about 75 to 100 per cent greater. Epidote and hornblende are not found below the Whitehorse in the area examined. Mica shows an increase, but not so obvious as it would be if some of the shales found above the Whitehorse zone were compared with some of the shales in the underlying Permian. Feldspar shows a very decided increase which would be in keeping with the presence of hornblende and epidote. Quartz forms the balance of the light minerals. This concludes the light and heavy mineral suites and shows that the Custer was derived from an entirely different source from any of the sandstones underlying it. No gradation is noted between Custer lithology and the lower sediments, which one would expect if there were no unconformity at the base of the Custer.

The mechanical analysis shows practically no difference between the Whitehorse and underlying sediments. There is, however, a slight tendency toward finer percentages in the Whitehorse. Considering the chart as a whole, it seems that the source of the Custer must have been considerably nearer than the source of the underlying Permian sediments. This applies to the Anadarko basin of Oklahoma only; otherwise, such minerals as hornblende and epidote, provided the epidote were not authigenic, would have disappeared, and the marked increase in tourmaline, garnet, and feldspar would have been less while the ratio of ilmenite-leucoxene would also show a marked increase. Analysis of the Custer which is farther away from the Wichita uplift shows an absence of hornblende and epidote. Near other igneous uplifts they again occur.

SOURCES OF MATERIAL AND CONDITIONS OF DEPOSITION

The source of the material composing the Custer and the conditions of deposition are very difficult to determine, as the Custer is quite uniform over very broad areas. A very good instance of this uniformity is the Anadarko Basin. The underlying red beds, or Permian, as they approach the Anadarko Basin become increasingly more clastic, especially around the southeastern end where gypsums are almost entirely absent. These red beds are largely composed of sandstones with some shales, and are not at all like their equivalents

toward the north or west, north of the Wichita Mountains. The beds above the Verden channel sandstone, however, do not change laterally into this basin. There is approximately the same amount of sandstone in the Whitehorse zone. There is an increase in the amount of anhydrite, probably being the thickest on the surface, about Cloud Chief with an increase in the amount of dolomites. This is due largely to the extending into Oklahoma of the west Texas Permian salt basin, as it is the farthest northeast extension of these deposits known at the present time. These deposits may be traced around the west end of the Wichita Mountains directly into the Permian salt basin of west Texas. This shows that the Anadarko basin was both depositional and structural during Permian time, while during Custer time it was quiescent. Probably the preservation of this anhydrite series around Cloud Chief and westward is due to a lack of solution and to later structural rejuvenation of the Anadarko basin, as field evidence shows that these anhydrites are always considerably thinner over structural highs.

In looking at the problem from a paleogeographic standpoint, the typical marine conditions are more and more pronounced the farther west and northwest the section is carried; the beds in Idaho and the Lower Moenkopie in Utah contain marine fossils, and farther west in California and northward the Upper Triassic beds are also present as marine formations. Also the Muschelkalk is present in California as a marine sediment.

It seems that there was an uplift during early Triassic time running north and south through the general area of east central New Mexico and up into Colorado, passing through the Sierra Diablo Mountains and just west of the Guadalupe Mountains. This condition apparently initiated a desiccating sea to the east into which were deposited the Castile, Rustler, and salt with their equivalents northward into Oklahoma and even as far north as western Kansas. Evidence for this is the wells of southeastern Colorado which penetrate an enormous thickness of Triassic with thin beds of anhydrite and dolomite, the lower part being quite arkosic. Coming southward into Texas the amount of clastics decreased, whereas anhydrites and salt with some gypsum and dolomite were deposited. It is interesting to note that in well samples the intervals of desiccation are remark-

ably shown, though they are not nearly so fine as the ones in Stassfurt, Germany. The individual sequence seems to be first wind-blown sands with fine red shales, next a thin bed of porous dolomite, then anhydrite, and lastly salt. Individual members of this series vary considerably, but in a number of wells as many as thirty or more of these sequences have been observed.

With this enclosed sea in mind, and with a barrier toward the west which could not have been very wide, the source of most of the materials would seem to have been from the east and possibly northeast and southeast. We do not know what was taking place throughout the Mississippi Valley during this time; however, Triassic sediments do occur along the east coast of the United States. Undoubtedly the whole area was subjected to considerable wind transportation, as the sandstones so characteristic of the Custer occur from Wyoming to the southwest part of Texas. Locally there must have been high areas, probably along the site of the present Rocky Mountains, which contributed sediments as the high percentage of feldspar would show, and also the presence of epidote and hornblende in the Custer which are not found locally in the red beds just below. The conglomerates of the Santa Rosa and Shinarump horizons are extremely well rounded and are only composed of the most resistant materials, showing that they have been transported for a very long time and a long distance. There are so many things concerning the early paleogeography of the Rocky Mountains which are not known, that it is practically impossible to form decided opinions at the present time.

THE UBEHEBE CRATERS AND EXPLOSION BRECCIAS IN DEATH VALLEY, CALIFORNIA

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ABSTRACT

Two little-known explosion craters on the west side of Death Valley, California, are described. A peculiar type of pebble, originally water-rounded, then concentrically spalled, is explained as the product of a superexfoliation process induced by volcanic heat.

Near the northern end of Death Valley, California, on a spur that extends north from Tin Mountain of the Panamint Range, and at a site slightly northwest from the elevation marked 3,925 feet on the Ballarat, California, quadrangle topographic sheet of the U.S. Geological Survey are two volcanic cones known as the Ubehebe craters (Fig. 1). Neither crater is shown on the topographic map, nor do the craters appear on the state's geological map of Inyo County.[2] The larger of the craters is well known locally, though it is not often visited by tourists. Very few people seem to be aware of the existence of the smaller crater which is higher up on the mountain. The larger crater, nevertheless, is approximately 2,000 feet wide at the top and 500 feet deep (Fig. 2). The smaller crater is estimated to be 500 feet wide at the top and 150 feet deep (Fig. 3).

The perfection of development of these craters approaches that of idealized diagrams of geological phenomena in textbooks. Even the geologically untutored visitor cannot fail to be impressed by the clear evidence they present of the effects of volcanic forces and will at the same time be intrigued by their novelty as scenic pieces. Originally developed with almost perfectly symmetrical forms, the craters have suffered very little from erosion. Such slight dissection

[1] The author is greatly indebted to Mr. O. B. Suhr who made possible the visit to the Ubehebe craters and who is himself a competent geologist. His name does not appear as co-author because illness has prevented him from critically going over this paper. The author alone is responsible for any errors, but much of the credit for the observations and deductions made is due to Mr. Suhr.

[2] Geological Map of Inyo County, California, geology by C. A. Waring, State Mining Bureau, 1917. Scale, 1 inch = 4 miles.

might be construed to be evidence of very recent origin. But the infrequent, cloud-burst type of precipitation of these desert regions could miss a particular area for tens and perhaps even hundreds of years. Further, the bottoms of the craters are covered with playa clay, and a field of volcanic ash situated to the south and east of the

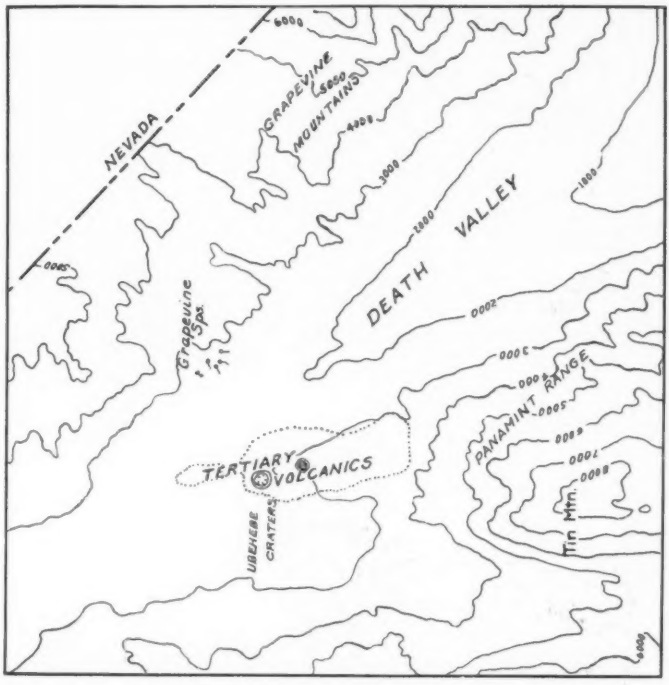

FIG. 1.—Sketch map to show the location of the Ubehebe craters. Designation "Tertiary volcanics" is from California State Geological Map of Inyo County.

smaller crater, which was apparently the source of the material in the ash field, has been very considerably dissected by running water (Fig. 4). This ash field may have been traversed by drainage from a wider area than that which could effect the erosion of the craters. Even so, it is not to be concluded that these craters are, in time of origin, as of yesterday. Due to the great porosity of the deposits, heavy rainfall goes into rather than over their surfaces—hence the

clay accumulations at the bottoms of the craters—and it is only after chemical weathering of the fragments brings about some degree of

FIG. 2.—East wall of the larger Ubehebe Crater. Note gullying of the interior of the crater although the surface of the fragmentary beds shows no signs of erosion. The view looks directly across Death Valley on Grapevine Springs. Photo by O. D. von Engeln.

FIG. 3.—The smaller Ubehebe Crater. View looking north. Photo by O. D. von Engeln.

consolidation that active dissection of the outer slopes of such cones takes place.

The two volcanic vents appear to be situated on fault line that extends parallel to the west side of Death Valley. Looking north from the rim of the larger crater the trace of this fault is marked by a low scarp developed in unconsolidated materials, desert fanglomerate with intercalated small basaltic flows, and beds of volcanic ash (Fig. 5). The fault plane appears to cut through the middle of the larger crater.

FIG. 4.—Dissected ash field to north and east of the smaller Ubehebe Crater. Photo by O. D. von Engeln.

As a consequence of the dissection, the interior of this crater has two very different aspects. On the east side it presents a steep wall of pink-to-red quartzite (Fig. 2). This rock has a shattered surface due to the volcanic explosion and is also gullied by rain wash concentrated by percolation through the overlying fragmentary beds. The western side of the interior of the crater is buried under fragmental volcanic materials with the exception of one point near the bottom, where a partly consolidated mass of white volcanic ash projects through the cover of loose darker stuff.

Extending completely around the rim of the larger crater to an estimated depth of 50 or more feet there is a strikingly banded deposit of light and dark layers (Fig. 5). The surface of this deposit is

dark and is made up of lapilli of vesicular basaltic lava, and quite black lava. The pieces are rather uniformly the size of chestnuts or small olives (Fig 6—3*A* and 4*A*). A few bombs of larger size are present, and there is a considerable admixture of cindery material. The lighter layers are made up of a mixture of the black lapilli, and, in greater part, of pebbles and fragments of quartzite and igneous

FIG. 5.—The upper edge of the west wall of the larger Ubehebe Crater and the trace of the fault break extending northward across the ash field on the floor of Death Valley. Note alternation of the light and dark layers of ejected materials. Photo by O. D. von Engeln.

rocks. These fragments and pebbles are of many shades and are of two contrasted kinds.

The one kind (Fig. 6—1*A*, 2*A*, and 7*A*) consists of angular fragments, chiefly of pinkish quartzite, tending to cubical form and measuring about ½ inch in each dimension. These pieces have the freshness and uniformity characteristic of specimens prepared by cracking up large pieces of rock for use by students individually in a laboratory class. They were quite obviously torn from the rock of the east wall of the crater by explosive eruptions.

The other (Fig. 6—5*A*–11*A*, inclusive, except 7*A*) material con-

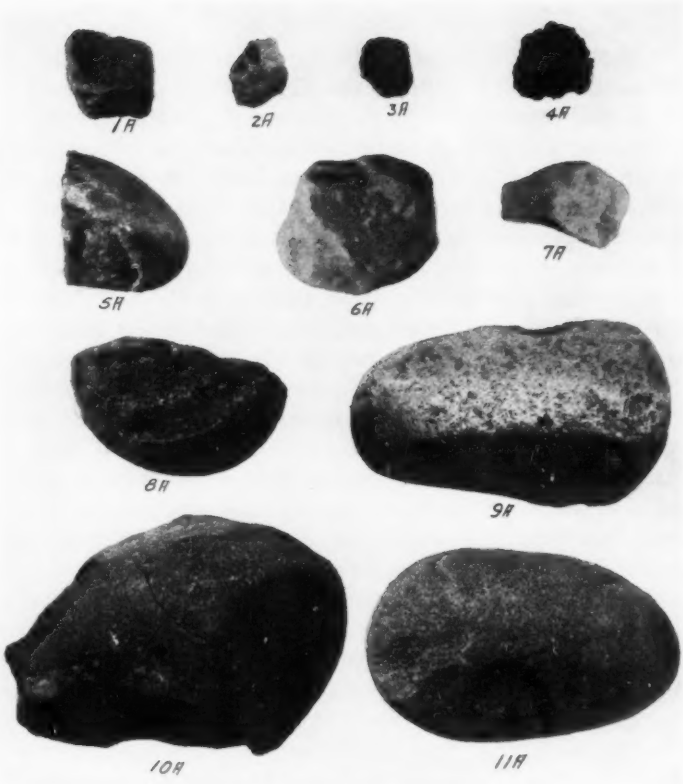

FIG. 6.—Fragments and pebbles from deposits on the rims of the Ubehebe craters. Dimension given is longest diameter of the specimen.

1A.—Red quartzite, 1 inch, characteristic cubical shape of many pieces.

2A.—Pink quartzite, $\frac{5}{8}$ inch.

3A.—Black basalt, $\frac{5}{8}$ inch.

4A.—Vesicular black lava, 1 inch.

5A.—Concentrically spalled quartzite pebble, $1\frac{1}{2}$ inches. Note how outer shell has been cracked off. Stream-rounded and split across the middle.

6A.—Quartzite, originally stream-rounded pebble like No. 5, except that almost whole of former pebble surface has been spalled off, 2 inches.

7A.—White quartzite, $1\frac{1}{2}$ inches, probably same source as Nos. 1 and 2.

8A.—Gneissic, originally stream-rounded pebble, elongated by pressure, $2\frac{1}{2}$ inches.

9A.—Pebble, syenitic rock, originally stream-rounded, now perfectly wind-faceted on two sides, spalled and stream-rounded on hidden side, $3\frac{1}{4}$ inches.

10A.—Large, gneissic pebble, stream-rounded like Nos. 5 and 6, shows fresh cracks in stream-rounded surface and perfect concentric spall on right, 4 inches.

11A.—Pebble like No. 9 except that facets not so perfect and stream-rounding more obvious, $3\frac{3}{4}$ inches.

sists of pebbles. These pebbles have peculiarities that do not seem to have been described previously. They average from 1 inch to 2 inches in diameter, hence are conspicuously larger than the quartzite fragments. Nearly all of the pebbles were originally distinctly stream rounded. Many of them have been split cleanly through the middle. A few have facets on two or three sides (Fig. 6—9*A* and 11*A*), though the faceted pebbles were sufficiently uncommon to be conspicuous. Other pebbles had fresh cracks running into them (Fig. 6—10*A*). The distinctive and marked peculiarity of the majority of the pebbles is that they display an irregular exterior so contoured that it preserves roughly the original water-rounded shape of the pebbles. This irregular exterior was clearly developed by spalling off the former smooth surface as a concentric peel of uneven thickness (Fig. 6—5*A* and 6*A*).

It was first conceived that these spalled pebbles had been broken out of the matrix of an old, well-consolidated conglomerate present under the quartzite beds that form the east side of the crater. The concentric spalling could then be attributed to the fact that the adhesion between the surface of the pebble and the surrounding materials was of greater strength than that of the cohesion within the pebble in resisting the disruptive action of the volcanic explosion. A slight further confirmation of such interpretation was the finding of one pebble that showed signs of having been elongated by pressure (Fig. 6—8*A*). But systematic search for a specimen that had a fragment of matrix adhering to a partially preserved surface, original to the pebble, failed in its purpose. Such pieces may be present, and, if they are, would be strong evidence in support of the interpretation first made.

On the other hand, pieces with adhering matrix should have been plentifully present if the source of the pebbles was an ancient consolidated conglomerate. Hence, the alternative explanation, that the pebbles are from the material of a recent desert fan that underlies the west side of the crater and has been buried by accumulation of fragmented volcanic stuff, appears to apply. This interpretation is also open to certain objections. It would seem to indicate that the upthrow side of the fault is the quartzite cliff on the east side of the crater, and that is the side toward Death Valley, the floor of which is

considered to be an area of depression. If, however, the east side of the Panamint Range is thought of as the back slope of a rotating fault block, a back slope that has its termination (under a deep cover of fanglomerate) against the steep, west-facing scarp of the Grapevine Mountains on the far side of Death Valley, then the faulting through the large Ubehebe Crater may be a secondary break resulting from the failure of the wedge along the axis of Death Valley to keep pace with the down-movement demanded by the rotation of the block comprising the Panamint Range. But the pebbles are much more stream rounded than those commonly found on the surface of the modern fans or in the bottoms of the washes cut into such fans. If the rounding of the ejected pebbles is interpreted to be a result due to a period of greater moisture and more continuous flow of streams than that of the present, then the fact that a few of the pebbles display the zweikanter and dreikanter (Fig. 6—9*A* and 11*A*) type of faceting attributed to wind erosion is difficult to explain, because such wind-fashioned pebbles are very uncommon in the surface deposits of the Death Valley desert and adjacent areas with similarly arid climates. Further observations must be made before these contradictory indications can be reconciled.

It seems, however, quite clear that the concentrically spalled, cracked, and split pebbles owe these characteristics to the fact that they were suddenly very highly heated in the volcanic blasts, and such superexfoliation process, introducing an extraordinary degree of differential expansion, produced these effects. The presence of even slight amounts of moisture in the pebbles would very greatly promote the concentric spalling under such conditions. The cubical quartizite fragments were produced by a similar disruption of the massive beds from which they were derived. The quartzite fragments could well be classified as explosion breccia, but that term would not serve so well for the modified pebbles.[1]

A layered deposit, built up as those about the Ubehebe craters are—of spalled, light-colored pebbles, water rounded and wind

[1] Conditions under which explosion breccias are produced and volcanic phenomena associated with their occurrence are well described in a paper by R. T. Walker, "Mineralized Volcanic Explosion Pipes," *Eng. and Min. Jour.*, Vol. CXXVI (1928), pp. 895–98, 939–42, 976–84.

faceted mingled with angular quartzite fragments and dark basaltic lapilli—would, upon consolidation, make a very peculiar rock. If such a bed were encountered in a series of strata of earlier geological times it would probably prove a considerable puzzle to the discoverer.

The smaller crater (Fig. 3) is especially interesting because of its perfection of form. As the material around its rim is very loose, a footstep makes a deep mark, one that might not be erased for many years by the denuding process effective there. As only few footprints were visible when these observations were made late in 1929 it is probable that the smaller Ubehebe Crater is little known. It is situated within a larger caldera depression, hence is an illustration of what Walker[1] calls the cone-in-bowl structure. This fact indicates that the site is one of recurrent volcanic activity. The smaller vent appears not to pass through the quartzite formation, because around its rim, mingled with lapilli, only the spalled conglomerate pebbles appear. Before the last explosive outburst this vent appears to have been plugged with lava, as a collar of vesicular basalt about 20 feet thick extends completely around the inside of the crater below an equal thickness of the fragmented material.

As Death Valley becomes increasingly popular and accessible to tourists through the construction of roads and provision of hotels, ever greater numbers of persons will discover these craters. One gets the impression when walking over the deposits that something pristine is being destroyed. It will be regrettable if no measures are taken to prevent visitors to these perfect geological monuments from trampling the deposits out of all semblance of their original condition.

[1] *Ibid.*, pp. 939–40.

THE DOUGLAS CANYON FLORA OF EAST CENTRAL WASHINGTON

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ABSTRACT

A fossil flora was found in sedimentary beds which are apparently conformable with the overlying Columbia River lavas in one of the side canyons of Moses Coulee, Washington. These beds are here designated as the Douglas Canyon formation. The flora indicates a late Miocene age. By comparison the Douglas Canyon formation seems to be equivalent to the Latah formation of Spokane, Washington. The late Miocene flora was mesophytic, whereas the present is xerophytic.

The fossil plant remains here discussed were collected by the writer in July, 1931, while working with a field party of the State of Washington Geological Survey under the direction of Dr. Malvin G. Hoffman, of the State College of Washington. The work of the survey party was confined to a study of Moses Coulee and the adjoining area. The exposed rocks consist principally of Columbia River lavas. In one of the side canyons sedimentary beds containing plant fossils were found beneath the flows. The location is in Douglas Canyon, above and below the waterfalls about $\frac{1}{2}$ mile from the canyon mouth, in the NW $\frac{1}{4}$ of the SW. $\frac{1}{4}$ of Sec. 30, T. 23 N., R. 24 E., Douglas County, Washington.

These sedimentary beds are here designated as the Douglas Canyon formation. The bottom of the formation was not seen. The section is apparently conformable with the overlying basaltic flows and is a well-stratified series of interbedded light gray to buff-colored arkosic sands and light to very dark gray shales, 35 feet thick, which dip 6° in a southerly direction. The plant remains were obtained from a thinly laminated lignitic shale bed approximately a foot thick, lying about 11 feet below the basalt contact.

The recognized species[1] are:

Populus heteromorpha Knowlton.
Populus lindgreni Knowlton.
Populus washingtonensis Knowlton.
Betula heteromorpha Knowlton.

[1] Catalogue Nos. 40618–37, Walker Museum.

FIG. 1.—Map of Douglas County, Washington, showing fossil locality

FIG. 2.—Douglas Canyon sediments overlain by Wenas basalts. One-half mile up Douglas Canyon. Uppermost sedimentary layer is 10 feet thick.

Betula largei Knowlton.
Castanea orientalis Chaney.
Quercus cognatus Knowlton.
Quercus simulata Knowlton.
Quercus treleasii Berry.
Ulmus speciosa Newberry.
Ficus washingtonensis Knowlton.
Laurus grandis Lesquereux.
Magnolia sp. Knowlton.
Prunus rustii Knowlton.
Meibomites lucens Knowlton.
Leguminosites bonseri Berry.
Celastrus spokanensis Berry.
Acer bendirei Lesquereux.
Paliurus hesperius Berry.
Wood, stems, bark, several species.

All the species are represented in the flora of the late Miocene Latah[1] formation of Spokane, Washington. The added significance of the position of the Douglas Canyon formation with regard to the basalts in comparison with the similar position of the Latah sediments indicates an equivalent age for both formations.

Other formations, some now considered to be late Miocene, containing identical species, are the Eagle Creek,[2] in Oregon and Washington; the Payette[3], in Idaho; the Mascall,[4] in Oregon; the Clarno,[5] in Oregon; the Bridge Creek,[6] of Oregon; and Miocene beds, in Yellowstone National Park[7] and California.[8]

[1] F. H. Knowlton, "Flora of the Latah Formation of Spokane, Washington, and Coeur d'Alene, Idaho," *U.S. Geol. Surv. Prof. Paper 140-A* (1926), pp. 30, 31, 34, 36, 38, 39, 40, 41, 43, 44, 45; E. W. Berry, "A Revision of the Flora of the Latah Formation," *U.S. Geol. Surv. Prof. Paper 154-H* (1929), pp. 242–48, 252, 254–57.

[2] R. W. Chaney, "The Flora of the Eagle Creek Formation," *Contributions from Walker Mus.*, Vol. II, No. 5 (1920), pp. 120–22, 124–27.

[3] F. H. Knowlton, "The Fossil Plants of the Payette Formation," *U.S. Geol. Surv. Eighteenth Ann. Rept.* Part 3 (1898), pp. 725, 728.

[4] R. W. Chaney, "The Mascall Flora," *Carnegie Inst. Wash. Pub. 349* (1925), pp. 26–27.

[5] F. H. Knowlton, "Fossil Flora of the John Day Basin, Oregon," *U.S. Geol. Surv. Bull. 204* (1902), p. 39.

[6] R. W. Chaney, "Geology and Paleontology of the Crooked River Basin," *Carnegie Inst. Wash. Pub. 346* (1927), pp. 66–67.

[7] F. H. Knowlton, "Fossil Flora of the Yellowstone National Park," *U.S. Geol. Surv. Mono. 32*, Part 2 (1899), p. 725.

[8] Leo Lesquereux, "Cretaceous and Tertiary Flora," *U.S. Geol. Surv. of the Territories*, Vol. VIII (1883), p. 251.

Of interest is the indicated striking difference between the late Miocene and the present climates of this region. The facies of the typically mesophytic Douglas Canyon flora indicates without doubt a temperate and moderately humid climate for the late Miocene. The present vegetation, which is typically xerophytic, is thriving in a desert climate.

Of biological interest in connection with the evolution of certain kinds of insects is the discovery of fossil gall impressions[1] on *Quercus cognatus*.

[1] A. D. Hoffman, "Miocene Insect Gall Impressions," *Botanical Gazette*, Vol. XCIII, No. 3 (May, 1932), pp. 341–42.

STUDIES FOR STUDENTS

THE SURFACES OF THE EARTH

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To the man walking over the ground the surface of the earth is the junction surface between the air and the land. To the man sailing on the sea the surface is where the ocean and the air meet. To the mathematician computing the geographic positions of triangulation stations the surface of the earth is an ellipsoid of revolution, a mathematical surface that can be described in mathematical terms. To the geophysicist the idealized surface of the earth is conceived of as being a level surface, a surface on which a mass could be moved, if friction were entirely absent, without the expenditure of work. The tidal experts look on the surface of the earth as mean sea level, as defined by the mean position of the surface of salt water determined at many places along the sea coast.

All of these surfaces are different, yet they are not very far apart. The maximum elevation of the land area is 29,141 feet above the surface of the sea. This is at the top of Mount Everest in the Himalayan Mountains in Northern India. The deepest depression of the solid surface of the earth is to the eastward of the island of Mindanao, Philippine Islands. There a depth of water of 34,219 feet was found by the German cruiser "Emden."

We are getting a correct knowledge of the configuration of the earth's surface by means of surveys and the resulting maps on which are shown the elevations or the slope of the ground. There are many areas, however, for which we have no adequate mapping data, but travelers and explorers passing through them have made sketches of rivers, plains, mountains, and swamps, so that we have a fair idea of what they are like.

As far as the ocean bed is concerned we are woefully lacking in data. Although some parts of the ocean area, especially those near

the continental coasts, have been surveyed rather intensively, there are many large areas (larger than the state of Texas) in which not a single determination of the depth has been made. In those vast areas may be buried mountain ridges, plateaus, or ocean deeps.

The geoid is the surface that over the oceans would be represented by the surface of ocean waters, if there were no disturbing influences. However, we do have such disturbing influences, notably the tide-producing forces of the sun and of the moon, the heat from the sun and the evaporation that it produces, the wind, the addition of water from the great rivers of the world, and the differences in temperature of the waters at the equator and at higher latitudes. If all of these effects were eliminated and we had no wind, no tide-producing effects, and no changes in temperature, etc., the water would lie continuously at one level along the shores. Over the land the surface of the water in narrow sea-level canals extending in imagination into the continents would define physically what we call the geoid surface. If a small body were barely floating in water conforming to the geoid surface, it could be moved from place to place without the expenditure of work, except that required to get the body in motion and to overcome the resistance of the water.

The relation of the geoid surface to the ellipsoid can be determined by means of geodetic data in the form of deflections of the vertical and values of gravity and can be delineated on a map.

The ellipsoid is a mathematical surface that most nearly fits the geoid. A section of the ellipsoid along a meridian would be an ellipse. The most accurate dimensions for the ellipsoid that most nearly represents the geoid surface of the earth were derived from geodetic data in 1909 at the office of the U.S. Coast and Geodetic Survey, Washington, D.C. The major semi-axis of the ellipse, that is, the radius of the earth at the equator, is 6,378,388 meters (3963.3 miles), and the semi-diameter along the axis of the earth which joins the north and south poles is 21,476 meters (13.3 miles) shorter than the equatorial radius. The ellipticity, or the flattening of the earth, is represented by the ratio of the difference in the semi-axes to the equatorial radius. The reciprocal of this ratio is 297.0. The ellipsoid, or figure of the earth, has been derived from geodetic data on more than one continent, and there is a fair agreement of the results.

Necessarily, the wider the area and the more abundant the geodetic data used, the better will the results be determined. The use of isostasy, or the principle that the irregular surface of the earth is due to irregular densities in the crust which fade out at a depth of about 60 miles below sea level, has made it possible to secure an ellipsoid from the area of the United States that probably fits very closely the geoid surface of the whole world. Necessarily, without the application of isostasy, an ellipsoid derived for a limited area cannot be expected to represent truly the mean geoid surface for the whole earth. If, for a continent, the mountains are in the interior and very high, the ellipsoid derived by methods in which isostasy is not considered will have dimensions that are too small. On the other hand, if the mountains of a continent are close to its edges and the interior is very low in altitude, the dimensions of the ellipsoid will be too large. If isostasy is considered, the deflections of the vertical caused by the irregular terrane and its isostatic compensation can be determined, and these effects can be eliminated in the computation of the figure of the earth or the ellipsoid.

The leveling nets of the United States and of Canada, involving 75,000 miles of first-order leveling, were recently adjusted in order to make the work more consistent. While making the adjustment, it was found that the mean sea-level determinations at different tidal stations along the coast did not define a level surface. Since all of these stations were connected to the network of levels, the results of the adjustment gave a very clear idea as to the extent to which the mean sea-level surface deviates from the geoid surface, or the ideal sea-level surface. If we take mean sea level at Galveston, Texas, as being the ideal sea-level surface, we find that the mean sea-level surface at St. Augustine, Florida, is 0.9 foot below Galveston. The mean sea-level surface at Portland, Maine, is 1.3 feet above that at St. Augustine. The mean sea level at Father Point on the Gulf of St. Lawrence, one of the tidal stations of Canada, is 1.5 feet above St. Augustine.

The level net adjustment showed a similar condition on the Pacific Coast. For instance, San Diego is 1.1 feet above Galveston; San Francisco is 1.1 feet above Galveston, and Seattle is 1.6 feet above Galveston. It will be noted that the water on the Pacific

Coast also apparently slopes uphill toward the north, for mean sea level at Seattle is above that of either San Diego or San Francisco.

Mean sea level is determined by a tide gauge. A staff, graduated to feet and tenths of a foot, is put up alongside a pier, or fastened to a specially driven pile, and an automatic device records the position of the surface of the water with respect to the zero graduation of the tide staff. This point of the tide staff is referred to objects ashore, called bench marks. From the average hourly values of the height of the water, over a period of about three years, we can derive with considerable precision the average position of the surface of the water or mean sea level with regard to the points on shore and the zero of the staff.

Leveling is done with such accuracy that an actual difference in the elevations of mean sea level at two tidal stations can be determined. In fact, the closing error of a circuit of level lines is at the rate of only about 0.15 mm. per km. The leveling net of North America is so intricate and there are so many connections and closed loops involving separate lines that the resulting elevations determined from the adjustment are much stronger than if only a single line were run from one place to another. Although the differences in mean sea level mentioned above are the best obtainable from the level net adjustment, they should not be considered as being correct out to the last decimal place; but it is believed that they are very close to the true differences in the elevations of the actual water surface and the ideal level surface called the geoid.

Other evidence of differences in mean sea level comes from the leveling across the Isthmus of Panama, executed by the engineers of the Panama Canal Commission, which showed that the mean sea level of the Pacific waters is 0.7 foot higher than the elevation of mean sea level on the Atlantic end of the Canal.

No extensive research has been made as to the causes of the deviation of the mean sea-level surface from the geoid, but it is believed that differences in density, caused by differences in temperature, and variations in salinity, in average barometric pressures and in prevailing directions of wind have much to do with deviations of the actual mean sea-level surface from the geoid.

It is interesting to know that in carrying on leveling operations

we have to deal with the actual form and position of equipotential or level surfaces at various heights above mean sea level. Along the coast we are working very close to sea level and, therefore, the equipotential surface is almost parallel with the water surface, but, in plateau regions or in mountains, the elevations are many thousands of feet above the sea-level surface. Some years ago a line of levels was run from San Diego, California, northeastward through Utah into Idaho and then northwestward to Seattle. The uncorrected levels showed that mean sea level at Seattle was more than 3 feet higher than mean sea level at San Diego. This was not wholly due to a tilting of mean sea-level surface nor to errors in the leveling, but it was due largely to the fact that the leveling was carried along a number of level surfaces, each of which was far above the sea-level surface at San Diego and at Seattle.

Mathematical theory shows that even outside a regular ellipsoid the distance between two given level surfaces is less at the poles than at the equator and it is for this reason that the line of levels run from San Diego to Seattle failed to close the leveling circuit by more than a meter. In order to test the leveling run through the high interior of the country, it is necessary to compute the effect of this non-parallelism of the level surfaces in order to be able to learn how much of the closing error of a loop is actually due to unavoidable errors of leveling.

It might be thought that this question of determining the surface of the earth has only academic importance, but the determination of the shape and size of the outer surface of the earth (whether the actual surface is the geoid or the ellipsoid, which deviates less than 300 feet from the geoid) is of the utmost importance to the navigator. The ships sail on the surface of the sea, and if the navigator did not have the exact knowledge of the dimensions of the earth as indicated on his chart, his dead reckoning and other kinds of navigation would all go awry. The engineer working on the land must also know the shape and size of the earth, for his maps must be accurate in direction, distance, and elevation.

The astronomer uses the dimensions of the earth in some of his work and he needs to know the dimensions with much refinement. The geodetic engineer in the leveling operations of a nation or, in

fact, of a continent must know the relation between the level surface, called the geoid, and the actual water surface which deviates from the geoid. Otherwise the level net cannot be properly fitted to the actual sea-level surface.

The ellipsoid is the surface that is really used more than any other by the mathematician, the chart-maker, and the map-maker. It is a surface that he can actually handle with facility. The geoid surface has its humps and hollows, some of which are rather small in area, and in any event it is most difficult to determine with any great degree of accuracy. The ellipsoid, on the other hand, can be used without difficulty by the engineer, cartographer, and the mathematician, for the ellipsoidal surface can be defined in mathematical terms and tables can be computed with which to construct the grid system or projection for the chart. With that network of lines, usually called meridians and parallels, the detailed topographic features needed by the user of the map or the chart can be shown in the correct locations.

From a scientific standpoint, it is the primary purpose of the geodesist to determine with ever increasing accuracy the dimensions of this ellipsoid and the relation of the geoid to it. The greatest possible accuracy will not be attained until all of the triangulation of the world on all of the continents has been connected together. Such a connection is possible, for even though America is separated from Europe and Africa by the Atlantic Ocean, it is separated from Asia at Cape Prince of Wales, Alaska, by only a comparatively few miles. It is feasible to make a connection by triangulation between Alaska and Siberia and then, if the triangulation nets of the Eastern and Western Hemispheres were carried to Bering Strait, the two great nets could be fitted together and a figure of the earth could be determined that would be so accurate that the geodesists thereafter might perhaps be free to spend all of their time on other scientific phases of earth studies and on the practical parts of geodesy.

NOTE ON THE FORMATION OF KAOLIN MINERALS FROM FELDSPAR

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ABSTRACT

The action of dilute hydrofluoric acid at about 225° C on a potash feldspar powder is shown to result in the formation of a kaolin mineral, probably kaolinite or dickite. Carbonic acid under 1,800 pounds pressure produced no apparent alteration of this feldspar after 156 hours treatment at 60° C.

Among the theories of the origin of kaolin deposits, there are two which may readily be tested by laboratory experiments. These are based on the attack of feldspar by carbonic acid or by fluorine compounds. The latter method was tried in 1886 by J. H. Collins,[1] who caused hydrofluoric acid vapor to pass through a heated lead tube which contained feldspar. Chemical analysis proved that the feldspar was rapidly converted into hydrated aluminum silicate, and microscopic observation indicated a close resemblance of this substance to kaolin.

It seemed desirable to continue these experiments using modern X-ray methods to verify the nature of the altered feldspar. Accordingly, a few grams of finely powdered potash feldspar were placed in a lead-lined iron bomb which had been nearly filled with 5 per cent hydrofluoric acid. The bomb and its contents were then heated to about 225° C for about 24 hours. After this treatment the powder which remained in the bomb was analyzed by the Hull X-ray diffraction method.

Table I affords a comparison of the diffraction patterns which were produced by the alteration product of the feldspar and by a natural kaolin mineral from Red Mountain, Colorado, as measured by McVay and Thompson.[2] The rather faint appearance of the diffraction lines which were produced by the altered feldspar made their measurement difficult and produced uncertainty in the second

[1] J. H. Collins, *Miner. Mag.*, Vol. VII (1886), p. 212.

[2] T. N. McVay and C. L. Thompson, *Jour. Amer. Ceram. Soc.*, Vol. XI (1928), p. 832.

decimal of the listed values. A general fogging was visible on the photographic film, and this appearance suggested that considerable amorphous material might have been present with the crystalline kaolin mineral.

TABLE I

COMPARISON OF INTERPLANAR SPACINGS IN ANGSTROM UNITS OF A NATURAL KAOLIN MINERAL* FROM RED MOUNTAIN, COLORADO, WITH POTASH FELDSPAR ALTERED BY HYDROFLUORIC ACID TREATMENT

Altered Feldspar	Natural Kaolin Mineral
.....	1.32 f
1.33 f†	1.33 vf
1.38 f	1.37 f
1.43 f	1.43 vf
.....	1.45 vf
1.49 f	1.49 m
1.55 f	1.55 vf
1.66 f	1.65 m
1.79 f	1.79 vf
1.88 f	1.85 vf
1.96 s	1.97 m
2.06 s	.....
2.19 m	2.20 f
2.26 f	.....
2.34 f	2.32 s
2.55 f	2.53 s
2.89 f	2.90 vf
3.08 m	3.06 vf
3.38 m	3.37 f
3.57 m	3.57 m

* T. N. McVay and C. L. Thompson, *Jour. Amer. Ceram. Soc.*, Vol. XI (1928), p. 832.

† The relative intensities of the diffraction lines are listed in the second columns under each compound, as "strong, medium, faint, or very faint."

The similarity of the values listed in Table I indicates that the hydrofluoric acid treatment transformed the feldspar into a kaolin mineral. The presence of two additional lines (2.06 and 2.26 A.U., respectively) on the diffraction pattern of the altered feldspar denotes the presence of some impurity, probably derived from the lead lining of the bomb. The nature of the kaolin mineral which was produced by the hydrofluoric acid treatment is uncertain. A comparison of the X-ray measurements of kaolinite and dickite as given

by Ross and Kerr[1] shows definite small differences in their diffraction patterns, but the diffuse appearance of the diffraction lines which were produced by the alteration product of the feldspar did not permit differentiation between these minerals.

The experiments dealing with the action of carbonic acid on powdered feldspar did not result in the formation of any kaolin mineral. In one of these experiments a quantity of potash feldspar was placed in a ball mill and covered with water. An atmosphere of carbon dioxide was introduced into the remaining space and the ball mill was caused to rotate for several days. No alteration of the feldspar after this treatment could be detected by the X-ray method.

In another set of experiments a greater concentration of carbonic acid was prepared by placing water in a brass bomb under 1,800 pounds pressure of carbon dioxide. A few grams of finely powdered potash feldspar placed in this bomb showed no apparent change after 156 hours' treatment. These trials were made at temperatures ranging from that of the room to about 60° C.

The failure of the experiments dealing with the action of carbonic acid, in the face of the geological evidence that many kaolins are produced by the decay of rock masses through such weathering agents, may have been due to the relatively short duration of the experiments in comparison with natural phenomena.[2]

[1] C. S. Ross and P. F. Kerr, *U.S. Geol. Surv. Prof. Paper 165-E* (Washington, 1931).

[2] The authors wish to express their appreciation to G. L. Clark for his kindness in extending the use of the X-ray equipment which was necessary in this investigation.

REVIEWS

Catalogue of the Marine Pliocene and Pleistocene Mollusca of California. By U. S. GRANT IV and HOYT RODNEY GALE. "Memoirs San Diego Society of Natural History," Vol. I. San Diego, 1931. Pp. 1036; figs. 15; pls. 32. $8.00.

With the publication of this monumental treatise and the recent appearance of the monographs by Weaver and Stewart, the centers of paleontologic research on Tertiary invertebrates seem definitely to have migrated to the West Coast. The present publication, which should never have been burdened with the somewhat onerous title of "Catalogue," grew out of an interesting experiment in higher education—a joint dissertation for the doctorate at Leland Stanford University. The results indicate nothing more clearly than that scientific partnerships so mutually reciprocal as that of Grant and Gale are likely to be the exception rather than the rule.

The memoir is divided as follows: pages 7–10, "Preface"; pages 19–77, "Summary of Stratigraphy"; pages 81–878, "Systematic Paleontology"; pages 880–958, "Plates and Their Explanation"; and pages 959–1036, "Index." The very valuable stratigraphic summary is almost entirely the work of Dr. Gale, whereas the systematic paleontology was chiefly prepared by Dr. Grant, although both authors are responsible for the many revisions in classification and the voluminous field data.

The Pliocene and Pleistocene stratigraphic data reported in this contribution result from distinct advances in methods of study in stratigraphic paleontology and sedimentation. Throughout this portion of the volume and in the "Introduction to the Systematic Paleontology" there is many a succinct and enlightening expression of stratigraphic and paleontologic principles. Much of the value of the memoir, however, lies in its simplification of nomenclatorial difficulties. As Grant aptly puts it, "The study of paleontology has some features in common with open-pit mining. . . . . A certain amount of worthless material must be shoveled up. . . . . In the case of conchological paleontology, the most vexatious part of this worthless over-burden is nomenclature and the problems connected with it. . . . ." Realizing this condition Grant and Gale have, with rare restraint, erected only twelve new generic and twenty-seven new specific

or varietal names. On the other hand they have been able to reduce literally scores of old specific and generic terms to the synonymy, and they have accorded rearrangement or reclassification to sixteen families.

It is natural, and it in no way diminishes the credit due the writers, that a memoir of the size and scope of this one should incorporate the ideas of many workers, and, indeed, the list of authorities to whom acknowledgments are due is unusually long. It is interesting in this connection to read that "under Professor Percy E. Raymond both writers received their introductions to paleontology, and a number of the ideas that they believe will prove most fruitful in the future . . . . can be traced to their source in Professor Raymond." Such tributes are particularly fitting inasmuch as brilliant students, characteristically though perhaps unconsciously, appropriate their instructor's pet theories; and in the past twenty years entirely too many "original ideas" in paleontology have had their unacknowledged source in Professor Raymond's classroom.

CAREY CRONEIS

ENLARGEMENT OF THE JOURNAL

When the *Journal of Geology* was launched in 1893 one of its active editors was R. A. F. Penrose, Jr. From that time till his lamented death in 1931 Dr. Penrose served on the editorial staff and contributed actively to the maintenance of the *Journal*. Now his helpfulness is continued through the magnificent legacy left in his will. This generous gift makes possible an increase in the size of the *Journal* together with certain other improvements. Beginning with this issue each number of the *Journal* will contain 112 pages instead of 96 as heretofore, thus providing more space for publication and more reading matter for the subscribers. The subscription price, however, will remain the same.

R. T. C.

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